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ASSOCIATIVE EFFECTS OF MIXED DIETS IN SHEEP

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ABSTRACT

Four suffolk wethers (40 kg) were fed in a 4 x 4 Latin square design to examine the effect of mixed diets of alfalfa hay (ALF) and corn grain (CG) on nutrient digestibility. Lambs were fed diets containing ALF:CG ratios of: (A) 100:00; (B) 67:33; (C) 33:67 or (D) 00:100 in a digestion trial. Digestibility coefficients of dry matter (DM), protein, starch, energy, neutral detergent fiber (NDF) and acid detergent fiber (ADF) were different ($P < .05$) between the all ALF and all CG diets. However, no differences ($P > .05$) were found in nutrient digestibilities across the mixed diets containing 33 and 67% CG. Expected nutrient digestibilities for the ALF-CG mixed diets, weighted by the algebraic sum of the nutrient digestibilities when these feedstuffs were fed alone, were compared to the nutrient digestibilities observed for the ALF-CG mixed diets. No differences ($P > .05$) were found between expected and observed digestibilities for DM, protein, starch, energy, NDF and ADF in the ALF-CG mixed diets. A linear relationship ($P < .05$) was found between nutrient digestion coefficients and the level of CG in the diet. Level of dietary CG accounted for 78, 41, 71 and 49% of the variation in the digestibility of DM, protein, energy and NDF, respectively. A quadratic relationship was observed ($P < .05$) between starch digestibility and the level of dietary CG.

(Key words: Associative Effects, Mixed Diets, Digestibility.)

INTRODUCTION

Associative effects of feedstuffs occur due to changes in digestion and metabolism of nutrients as a result of combining two feedstuffs in ruminant diets. Classical

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research conducted by Armsby (1917), Forbes (1933), Kriss (1943) and Swift and French (1954) reported a reduction in digestibility when grains were added to roughage diets. More recent studies have documented that when mixed grain and roughage diets are fed, the nutritive value of the feedstuffs is dependent on their combination with other ingredients (Byers et al., 1975 a,b; Kromann et al., 1975; Woody et al., 1983). Some researchers have concluded that associative effects in mixed diets occurs from a reduction in fiber digestion (Orskov and Fraser, 1975) while others have reported a depression in starch digestion (Zinn and Owens, 1980; Joanning et al., 1981). In contrast, others have found no associative effects present in mixed grain-roughage diets (Tyrrell and Moe, 1973; Preston et al., 1975). Thus, the presence of associative effects in mixed grain and roughage diets is unclear.

The objectives of our study were to determine the nutrient digestibility of diets with varying proportions of alfalfa hay and corn grain and to determine whether the nutrient digestibility of these mixed diets were equal to the algebraic sum of the nutrient digestibility when these feeds were fed alone.

MATERIALS AND METHODS

Four Suffolk wether lambs (40 kg) were fed in a 4 x 4 Latin square design to examine the influence of mixed diets of alfalfa hay (ALF) and corn grain (CG) on nutrient digestibility. Lambs were assigned at random to be fed diets containing ALF:CG ratios of: (A) 100:00; (B) 67:33; (C) 33:67 or (D) 00:100 in a digestion trial (table 1). Experimental diets were balanced to provide the same level of total protein. A mineral-vitamin supplement was added to meet NRC (1976) requirements for calcium, phosphorous, trace mineralized salt and vitamins A and D. Diets were ground through a 24/64 mm screen and thoroughly mixed. Lambs received feed and water ad libitum. Lambs were fed twice daily, unconsumed feed was weighed, recorded and discarded.

The lambs were housed in individual pens (130 x 130 cm) for a 10 d adaptation to their respective diets. Following adaptation they were transferred to individual metabolism crates (60 x 122 cm) for 5d collection period during which total fecal and urinary outputs were collected. Following each collection period the lambs were rotated to the next diet and the procedures repeated.

Total fecal collections were made on a daily basis for each lamb. Daily fecal outputs were weighed and mixed, and a 10% (by weight) aliquot was saved for analysis. At the end of the collection period, the daily samples were weighed and dried to a constant weight in a forced-draft drying oven maintained at 95 C. Dry matter values were calculated and averaged for the respective collection periods. These daily samples were then passed through a microhammer mill and composited for each lamb's collection period. Subsamples of this composite were ground through a 2 mm screen in a Wiley Mill and used for subsequent analyses.

Urine production was collected daily into 3-l plastic containers containing 23 ml of 50% (v/v) H_2SO_4. Urine volume was recorded and mixed, and a 25% (by volume) subsample was filtered through glass wool and stored at 3 C. At the end of the collection period, urine samples of each wether were mixed and a 10% subsample was frozen (-20 C) for subsequent analyses.

Gross energy determinations were made on the feed and fecal samples using bomb calorimetry as described by procedures outlined by Parr Instrument Company (1960). Acid detergent fiber (ADF), ether extract (EE), lignin and ash were determined by AOAC (1980) procedures. Neutral detergent fiber (NDF) of the feed and feces was determined by the method described by Van Soest and Wine (1967). Total nitrogen content of feed, feces and urine were measured by micro-Kjeldahl technique (AOAC, 1980). Feed and fecal starch determinations were made by a modification of MacRae and Armstrong (1968) procedure. Samples were gelatinized by autoclaving for 1 hr at 130 C. The gelatinized product was incubated at 60 C at a pH of 4.5 for at least 24 hr. The final glucose was determined using a glucose-oxidase reagent according to Sigma Chemical Company (1982).

Statistical analysis of results from this study was accomplished by analysis of variance procedure described by Steel and Torrie (1960). Treatment means were compared using Duncans (1955) Multiple Range Test. The data were further analyzed by least-squares regression analysis (Snedecor and Cochran, 1967).

RESULTS AND DISCUSSION

Digestibility of DM, protein, starch, energy, NDF and ADF for the CG diet was higher ($P<.05$) than the all ALF diet (table 2). However, nutrient digestibilities for the mixed diets containing 33 and 67% CG were similar. When regression equations were developed by analyzing across all diets, a linear ($P<.05$) relationship was found between the level of CG in the diet and DM ($R^2 = .78$), protein ($R^2 = .41$), energy ($R^2 = .71$), NDF ($R^2 = .49$) and starch ($R^2 = .50$) digestibility (table 3).

Expected nutrient digestibilities for the ALF-CG mixed diets, weighted by the algebraic sum of the nutrient digestibilities of these feedstuffs when fed alone, were compared to the nutrient digestibilities observed for the ALF-CG mixed diets (table 4). No differences ($P>.05$) were found between the expected and observed digestibilities for DM, protein, starch, energy, NDF and ADF for the ALF-CG mixed diets.

Our results are supported by Ledoux et al. (1985) who fed steers corn diets that were supplemented with varying increments of fescue hay and reported that DM and starch digestibility increased linearly ($P<.05$) with increased levels of corn. Additional studies by Brink and Steele (1985) found a linear ($P<.01$) increase in total tract and ruminal starch digestion as CG in the diet increased from 50% to 90%. The fact that Slyter (1976) found a decrease in rumen pH and reduced rumen motility in high grain diets may account for the increase in starch retention time and improved digestibility.

Further studies by Kromann et al. (1975) reported a linear relationship between CG and digestible energy, metabolizable energy and net energy values when lambs were fed corn diets supplemented with increments from 0 to 100% of dehydrated alfalfa. A linear relationship between dietary CG and digestible energy is in agreement with the results of Blaxter and Wainman (1964), Clemens et al. (1968) and Asplund and Harris (1971). Also, Wainman et al. (1976) conducted numerous feeding trials and concluded that associative effects were not present in mixed grain-roughage diets. Preston et al. (1975) summarized three Ohio experiments involving 280 steers and reported that net energy values for grain and silage were constant as the ratio of added grain to silage varied.

A quadratic relationship was observed between starch digestibility and the level of dietary CG (figure 1). This may be due to the high quality of alfalfa hay that was fed. Improvements in digestibility over the predicted values have also been reported by Brandt and Klopfenstein (1986) who fed lambs either low or high quality alfalfa or brome hay at 0, 15, 30, or 100% of the diet. In their study, there were positive associative effects present on digestibility of DM and NDF when the diet contained 30% of each hay fed. Also, Heavens (1978) reported positive associative effects present on the digestibility of cell wall constituents when alfalfa hay was supplemented at 33% of the diet containing low quality timothy hay.

In contrast, others have found negative associative effects present in mixed diets (Byers et al., 1975 a,b; Kromann et al., 1975; Joanning et al., 1981; Woody et al., 1983). Joanning et al. (1981) reported that depressions in starch, NDF and protein digestibility accounted for 59, 26 and 14% of the depression in DM digestibility for mixed immature silage-grain diets and 53, 36 and 10% of the depression in DM digestibility for mixed mature silage-grain diets, respectively. Also, Wheeler (1977) reported that depressions in starch, NDF and protein digestibility accounted for 50, 40 and 7% of the depression in DM digestibility in mixed diets, respectively. Associative effects may also alter the net energy value in growing and finishing steer diets (Lofgreen and Garrett, 1968; Byers et al., 1975 a,b; Woody et al., 1983).

As concluded in our study, there was no depression in nutrient digestibility or negative associative effects found in the mixed diets. This may be due to the physical form of the diets which can influence digestibility. Alfalfa hay and corn grain in our study were finely ground. In support of this theory, Kromann et al. (1975) found no interaction for digestible energy, metabolizable energy and net energy values when sheep were fed pelleted diets of dehydrated alfalfa and corn. However, in an earlier study, Kromann (1967) fed non-pelleted diets of mixed alfalfa hay and sorghum grain and found associative effects present for digestible energy, metabolizable energy and net energy values. Other workers (Moe et al., 1973; Wilson et al., 1973) have also found depressions in DM digestibility in mixed diets when corn was fed either whole or coarse ground.

In summary, the presence of associative effects in mixed grain-roughage diets, whether positive or negative, is variable. From the results of our data and past research, it is concluded that there are several factors that influence nutrient digestibility. These include the physical form of the diet, level of DM intake, proportion of grain-roughage mixture and the type and quality of forage.

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Table 1. Ingredients and Chemical Composition of Alfalfa Hay (ALF) and Corn Grain (CG) Diets

Item	ALF:CG 100:00	67:33	33:67	00:100
Ingredients:		% dry matter		
Alfalfa hay	99.0	66.7	33.6	
Corn grain		29.8	54.7	79.5
Soybean meal		.3	7.6	15.0
Urea		1.0	1.0	1.0
Mineral supplement[a]	.88	2.2	3.4	5.0
Vitamin premix[b]	.02	.02	.02	.02
Chemical composition:				
Dry matter	88.7	89.0	88.0	86.7
Crude protein	18.5	20.9	19.1	17.8
Starch	11.6	28.2	42.2	57.7
Neutral detergent fiber	53.3	44.0	36.2	24.5
Acid detergent fiber	34.5	22.8	18.3	4.6
Gross energy, kcal/g	4.4	4.1	4.2	4.2

[a]Contains ground limestone, dicalcium phosphate and trace mineralized salt.
[b]10,000 IU vitamin A/g and 3,000 IU vitamin D/g.

Table 2. Nutrient Digestibilities of Mixed Alfalfa Hay (ALF) and Corn Grain (CG) Diets

Item	ALF:CG 100:00	67:33	33:67	00:100	SE[a]
	%				
Dry matter	58.1[b]	67.5[c]	71.3[c]	82.3[c]	4.5
Crude protein	67.3[b]	74.6[bc]	74.1[bc]	81.9[d]	3.2
Starch	90.1[b]	97.2[c]	98.4[c]	99.0[c]	1.5
Energy	58.3[b]	67.5[bc]	74.7[bc]	82.6[d]	3.2
Neutral detergent fiber	50.4[b]	59.7[bc]	62.5[bc]	74.4[c]	4.8
Acid detergent fiber	48.7[b]	49.4[c]	51.5[c]	56.3[c]	5.1

[a]Standard error of the mean.
[b,c,d]Means in same row with unlike superscripts are different ($P < .05$).

Table 3. Regression of Corn Grain (CG) on Dry Matter, Protein, Starch, Energy and Neutral Detergent Fiber Digestibility

Nutrient	Regression equation	r^2
Dry matter	Y = 58.2 + .231 (%CG)	.78
Crude protein	Y = 68.0 + .129 (%CG)	.41
Energy	Y = 58.5 + .240 (%CG)	.71
Neutral detergent fiber	Y = 50.6 + .223 (%CG)	.49
Starch	Y = 92.0 + .083 (%CG) -.002 (%CG^2)	.50

Table 4. Observed and Expected Nutrient Digestibilities of Mixed Alfalfa Hay (ALF) and Corn Grain (CG) Diets

	ALF:CG			
Item	100:00	67:33	33:67	00:100
	% dry matter			
Dry matter				
Observed	58.1	67.5	71.3	82.6
Expected		66.2	74.4	
Change, %		+1.9	-4.2	
Crude protein				
Observed	67.3	74.7	74.1	81.9
Expected		72.1	77.1	
Change, %		+3.6	-3.9	
Starch				
Observed	90.1	97.2	98.4	99.0
Expected		93.0	96.1	
Change, %		+4.5	+2.4	
Digestible energy				
Observed	58.3	67.5	74.7	82.6
Expected		65.5	74.2	
Change, %		-3.1	-.7	
Neutral detergent fiber				
Observed	50.4	59.7	62.5	74.4
Expected		58.3	66.4	
Change, %		+2.4	-5.9	
Acid detergent fiber				
Observed	48.7	49.4	51.5	56.3
Expected		51.2	53.2	
Change, %		-3.5	-4.1	

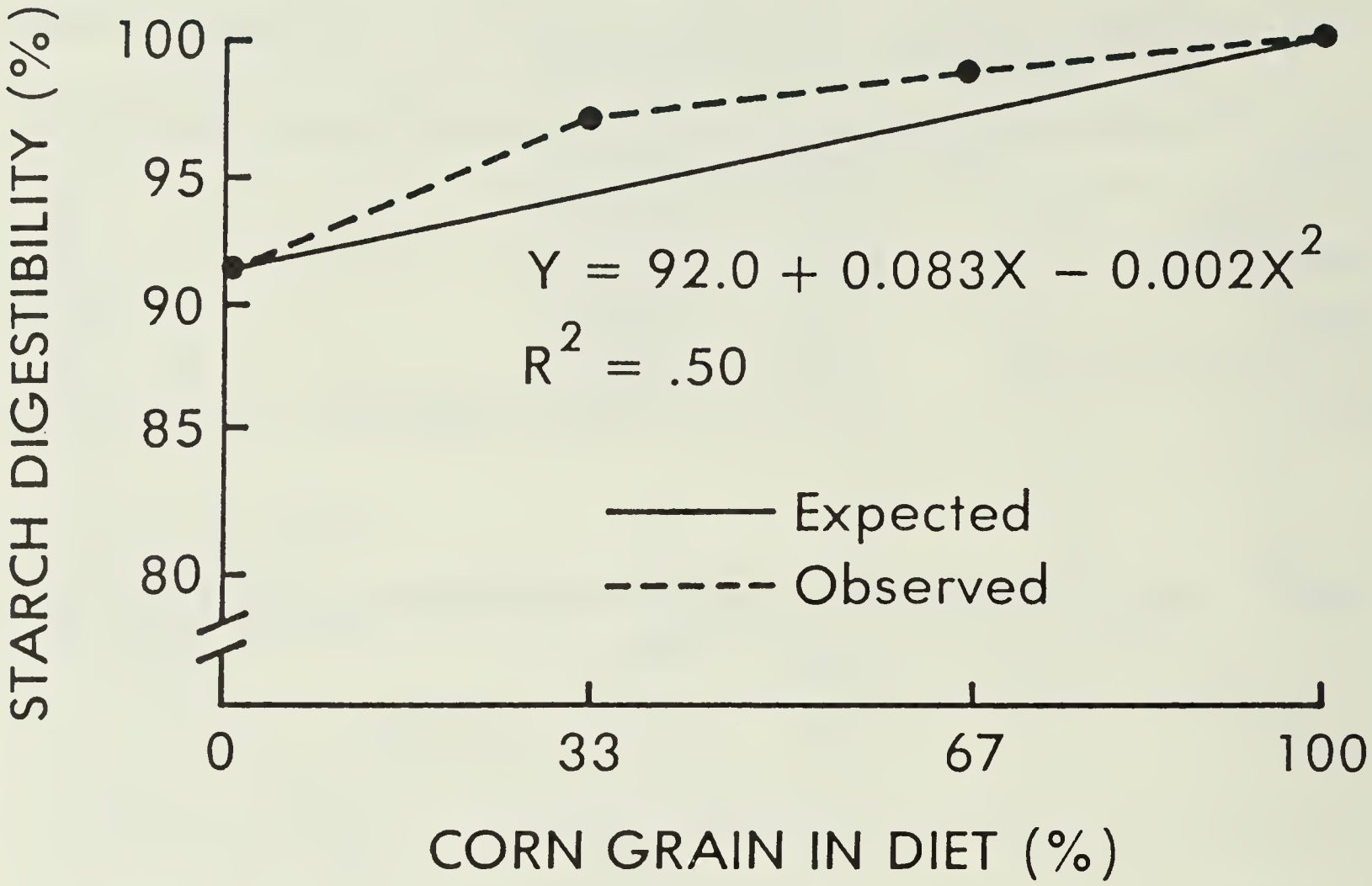

Figure 1. Relationship between diet corn grain level and starch digestibility.

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THE EFFECTS OF TWO ZERANOL PREWEANING IMPLANTS ON THE SUBSEQUENT REPRODUCTIVE PERFORMANCE OF BEEF HEIFERS

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ABSTRACT

Eighty-seven spring born heifer calves in three trials were assigned to receive either 0 or 2 Zeranol implants during the suckling period to study the effect of Zeranol on subsequent reproductive performance. In trial 1 heifers were stratified by weight and age at 73 ±6 d to either a control group or a treatment group which received one 36 mg Zeranol implant followed by a second implant at 157 d of age. In trial 2 every other heifer born served either as a control or received one 36 mg Zeranol implant on day one followed by a second implant at 90 ±8 d. In trial 3 heifers were assigned by weight and age to either a control group or a treatment group which received one 36 mg implant at 35 ±9 d and a second implant at 120 d of age. No differences ($P > .05$) in percent of the heifers exhibiting estrus following synchronization or in percent conception rate during the breeding season were observed in trials 1 and 3. In trial 2 fewer ($P < .05$) implanted heifers than control heifers conceived during the breeding season comparing 64.2% vs. 91.6%. In trial 2 implanted heifers had larger ($P < .05$) pelvic areas than non-implanted heifers. Implanted heifers in all three trials had higher ($P < .05$) average daily gains (ADG) and adjusted weaning weights than non-implanted heifers. This study suggests that (1) implanting heifer calves twice preweaning will improve gain performance and increase weaning weights, (2) if the first implant occurs on or after 35 d of age yearling reproductive performance will not be affected, (3) implanting at birth reduces yearling conception rates.

INTRODUCTION

Zeranol, known commercially as Ralgro, is a widely used anabolic agent that has been shown to increase weight gain and improve feed conversion in steers and heifers. The affects of Zeranol on the performance of finishing cattle is well documented: Borger et al., 1973; Baker and Ganyou, 1983; and Vanderwert et al., 1983. Zeranol has also been approved for implanting young calves prior to weaning. Zeranol, when implanted preweaning, has been demonstrated to have a beneficial effect on the weight per day of age and on the weaning weight values of nursing calves (Walker, 1981). Considerable data has also been generated demonstrating that steer and heifer calves implanted with Zeranol preweaning also respond positively (have an increased average daily gain and improved feed efficiency) to Zeranol when it is reimplanted post weaning (Ralgro News, 1983). Little data is available, however, regarding the efficacy of preweaning Zeranol implantation of heifer calves on their subsequent reproductive performance. What data is available is somewhat contradictory.

Muncy, et al. (1980) found that implanting heifer calves with Zeranol will suppress pubertal development. Ott, et al. (1982) found that implanting yearling heifers prior to the breeding season did not affect pregnancy rate but did result in conception occurring later in the breeding season.

Cow-calf producers make their initial replacement heifer selection at weaning. Currently, most producers do not implant their heifer calves prior to weaning because little is known about what affect Zeranol has on future reproductive performance. Consequently, the producer is not receiving the greatest preweaning performance possible from those heifer calves that are not kept as replacements.

OBJECTIVE

The objective of this study was to examine the effects of implanting suckling heifer calves with Zeranol on subsequent reproductive performance. Criteria measured were (1) rate of gain and feed efficiency to weaning; (2) physiological abnormalities at weaning and one year of age; (3) fertility at a synchronized estrus; (4) ease of calving of first calf; (5) milk production of first lactation and (6) conception rate during the breeding season following the birth of the first calf.

MATERIALS AND METHODS

During the calving seasons of 1982, 1983 and 1984 Chianina crossbred heifer calves were assigned to receive either 0 or 2 Zeranol implants preweaning to study the effect of Zeranol on subsequent reproductive performance (table 1). In trial 1, 25 heifers were stratified by weight and age at 73 days of age into either a treatment group or a control group. In the treatment group 13 heifers received one Zeranol implant (3-12 mg pellets) at 73 d ±6 d and another implant 82 d later at 155 d of age. In trial 2 every other heifer born received one Zeranol implant on day one and again 90 d ±8 d later. Accordingly, this procedure resulted in 14 heifers receiving two Zeranol implants preweaning and 12 heifers serving as controls. A total of 26 heifers were enrolled in trial 2. In trial 3, 36 heifers were stratified by weight and age at 35 d ±9 d into either a treatment group or a control group. In the treatment group 18

heifers received one Zeranol implant at 35 d ±9 d and another implant 85 d later at 120 d of age.

All heifers in each trial were creep fed on Pinpointer computer feeders which allowed for individual feed consumption to be recorded. All heifers in each trial were fed the same creep feed (table 2). While creep feed was provided from birth, actual consumption was not measured until approximately day 60 postpartum. Weaning weights are a reflection of adjusted 205 day steer equivalent weaning weights calculated according to Carr and Ricketts (1978). Average daily gain values reflect actual ADG as measured from birth to weaning. Following weaning all heifers within each trial were handled as one herd unit and were fed a corn silage based diet according to NRC estimates.

In trials 1, 2, and 3 all heifers were synchronized at 13-14 months of age and then bred at one timed insemination followed by pasture exposure to a bull for 60 days.

During trial 2 heifer calves were phenotypically scored at weaning for condition, conformation and frame size according to the Illinois Beef Performance Testing Procedures. In addition, each heifer was given a phenotypic abnormality score. The abnormality score included a visual examination of udder and vulva development, a generally coarse appearance, and abnormally large tailheads. According to the abnormality score each heifer was assigned a value between one and seven (one = normal, seven = abnormal). All phenotypic scores reflect the mean value of three technicians working independently. When the heifers in trial 2 were approximately one year of age, they were again scored for phenotypic abnormalities and were measured for size of the pelvic canal with a Rice Calipers. Size of the pelvic area was calculated by multiplying height times width. At the same time each heifer's reproductive tract was examined by rectal palpation and scored as either normal size or infantile. Any abnormalities observed were also recorded.

During trial 2 all heifers were rectally palpated 45 days following the end of the 60-day breeding season. All open heifers were culled at this time. Culled heifers were slaughtered within two weeks and their reproductive tracts were analyzed for abnormalities. All bred heifers were allowed to calve. Subsequent calving occurred during February and March of 1986. Ease of calving was measured subjectively according to the following procedure:

1 = no difficulty — no assistance
2 = minor difficulty — some assistance
3 = major difficulty — calf pulled
4 = Caesarian section — very difficult
5 = abnormal presentation

Each calf was weighed at birth and length of the rear cannon bone was measured. All calves were implanted with 3-12 mg pellets of Zeranol at birth. Reimplantation occurred 80 days later. A creep feed was provided to all the calves from birth until weaning.

Subsequent fertility of the first calf heifers (those implanted with Zeranol preweaning and controls) was measured according to conception rates to a timed insemination followed by a 60 day natural breeding season. These conception rates were determined by rectal palpation 45 days following the end of the breeding season.

Administering Zeranol preweaning and its effect on the subsequent milk production of the first calf heifer was determined by two methods. Method one consisted of calculating the adjusted 205 day weaning weight ratio of their calves and comparing the resulting values between implanted and nonimplanted heifers. The second method consisted of milking the heifers on one day of each month from calving through weaning via vacuum machine and then calculating an average 4% fat corrected milk production for each cow.

When each heifer's first calf was weaned, trial 2 was terminated. This occurred on September 9, 1986.

Performance data were analyzed by least squares analysis of variance and reproductive data were analyzed by Chi-square procedures according to procedures outlined by Neter and Wasserman (1978).

RESULTS AND DISCUSSION

The results of trial 1 can be found in table 3. No differences ($P > .05$) in percent of the heifers exhibiting estrus following synchronization or in percent conception rate during the breeding season were observed between the two treatments. Average daily gains were significantly higher for the heifers receiving Zeranol comparing 1.10 kg vs. 1.01 kg. Hence, adjusted 205 d weights were also higher ($P < .05$) for the implanted heifers comparing 226.4 kg to 207.3 kg. While differences ($P < .05$) in ADG and adjusted 205 d weights were observed, no significant differences in average daily feed intake (ADF) or G:F values were found. Trial 1 suggests that two Zeranol implants preweaning improve gain performance without decreasing yearling reproductive performance when the first implant does not occur before 73 d of age.

The results of trial 2 can be seen in tables 4, 5, and 6. ADG preweaning were different ($P < .05$) comparing 1.32 kg vs. 1.05 kg. Likewise adjusted weaning weights were different at the 10% confidence level and approached significance at ($P < .05$). Again ADF and G:F ratios were not different ($P > .05$) between implanted and non-implanted heifers. While no differences ($P > .05$) in estrus exhibition following synchronization were observed, heifers implanted at birth and again at 90 d did tend to trend lower numerically in percent exhibiting estrus comparing 85.7% vs. 91.7%. Significantly fewer implanted heifers conceived during the breeding season comparing 64.2% vs. 91.6%. Following rectal palpation all open heifers were slaughtered and their reproductive tracts were examined. For the most part these open heifers were observed to have small inactive or infantile ovaries (table 6). This trial would suggest that implanting Zeranol at birth may decrease yearling reproductive performance.

At weaning heifers were (1) given a numerical frame score, (2) measured for hip height, (3) given condition scores and (4) given phenotypic abnormality scores. No differences ($P > .05$) in any of these characteristics were noted between the implanted and non-implanted heifers.

Just prior to the breeding season all the heifers in trial 2 were measured for height and width of the pelvic opening with a Rice Calipers. Size of the pelvic opening was then calculated multiplying height times width. Implanted heifers had larger ($P < .10$) pelvic openings than non-implanted heifers but no difference was

observed at the 5 percent level of confidence. In addition, yearling hip heights, weights, condition scores and phenotypic abnormality scores were not different ($P > .05$) between the two groups of heifers. This data suggests that implanting Zeranol at birth improved gain performance to weaning without altering post weaning performance other than fertility as discussed previously.

All those heifers in trial 2 that conceived were allowed to calve. Calving ease scores were obtained as were birth weights and weaning weights of each heifer's first calf. In addition, each heifer was milked once each month during her first lactation by vacuum machine and an average daily 4% fat corrected milk production (4% FCM) was calculated. No differences ($P < .05$) in any of these performance parameters were found, regardless of implant treatment.

The results of trial 3 can be found in table 7. No differences ($P > .05$) in the percent of the heifers exhibiting a synchronized estrus or in percent conception rate during the breeding season were observed between the two groups. ADG were significantly higher for those heifers receiving Zeranol (1.18 vs. 1.04 kg.). Therefore, adjusted 205 d weights were also higher ($P < .05$) for the implanted heifers comparing 286.9 kg to 254.1 kg. As in trial 1 ADF and G:F values were not different ($P > .05$) between the two treatments. Trial 3 suggests that two Zeranol implants preweaning improve gain performance to weaning without decreasing yearling reproductive performance when the first implant occurs as early as 35 d of age.

CONCLUSION

In summary, our study suggests that (1) implanting heifer calves twice with Zeranol preweaning will improve gain performance and increase weaning weights. (2) If the first implant occurs at either 35 d or 73 d no adverse effects on postweaning reproductive performance will be observed. (3) If, however, the first implant occurs at birth the producer should expect to observe reduced yearling conception rates. It should be noted that at the present time implanting heifers with Zeranol which are to be kept for breeding purposes is not approved by the Food and Drug Administration.

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Table 1. Experimental Design

Trial No.	Treatment	No. of Heifers	Implant Times
1	+Ralgro	13	73 ±6 d, 157 ±d
	-Ralgro	12	
2	+Ralgro	14	Od, 90 ±8 d
	-Ralgro	12	
3	+Ralgro	18	35 ±9 d, 120 ±9 d
	-Ralgro	18	

Table 2. Creep Feed Composition

Item	Percent of Diet
Corn cobs (IFN1-02-782)	20.5
Alfalfa hay (IFN1-00-068)	15.5
Oats (IFN4-03-309)	24.0
Corn (IFN4-02-935)	20.0
Soybean meal (IFN5-04-064)	20.0

Table 3. Reproductive and Performance Data of Trial 1

Treatment	Heifers exhibiting estrus %	Conception rate %	ADG[a] kg	205 d wt[b] kg	ADF[c]	G:F[d]
+Ralgro	61.5	92.3	1.10 ±.09*	226.4 ±20.2*	3.27 ±.5	.34 ±.07
-Ralgro	54.6	90.9	1.01 ±.07*	207.3 ±18.4*	3.00 ±.6	.34 ±.05
Significance level	P >.05	P >.05	P <.05	P <.05	P >.05	P >.05

[a]Average daily gain.
[b]Adjusted 205 d steer equivalent weaning weight.
[c]Average daily creep feed intake.
[d]Gain to feed ratio.

Table 4. Reproductive and Performance Data of Trial 2

Treatment	Heifers exhibiting estrus %	Conception rate %	ADG kg	205 d wt kg	ADF kg	G:F	Weaning frame score[b]	Weaning condition score	Weaning abnormality score	Weaning hip height (cm)
+Ralgro	85.7	64.2*	1.32 ±.26*	310.9 +56.3	4.4 ±1.3	.31 ±.09	5.5 ±.9	4.2 ±.6	1.0 ±.1	113.7 ±6.4
-Ralgro	91.7	91.6*	1.09 ±.28*	282.8 ±22.2	4.3 ±.7	.28 ±.06	5.9 ±.8	4.3 ±.5	1.0 ±.1	119.5 ±14.5
Significance	P >.05	P <.05	P <.05	P <.10[a]	P >.05	P >.05	P >.05	P >.05	P >.05	P >.05

[a]Approaches significance at the P <.05 level of confidence.
[b]Scores ranged from 1-7, 1 = small and 7 = large.

Table 5. Yearling and Two Year Old Data of Trial 2

Treatment	Yearling Pelvic area (sq. cm.)	Yearling hip height (cm)	Yearling weight (kg)	Yearling condition score[a]	Yearling abnormality score[b]	Calving ease score first calf	Birthweight first calf (kg)	4% FCM (kg)
+Ralgro	198 ±15.1	125.3 ±5.6	341.9 ±30.3	4.2 ±.6	1.0 ±.3	1.4 ±1.3	41.7 ±5.8	4.4 ±.8
-Ralgro	185.8 ±21.6	127.5 ±5.1	346.7 ±27.1	4.2 ±.6	1.0 ±.3	1.8 ±1.1	42.9 ±4.2	4.7 ±.8
Significance	P <.10	P >.05	P >.05	P >.05	P >.05	P >.05	P >.05	P >.05

[a]Scores ranged 1-7 with 1 = thin and 7 = fat.

[b]Scores ranged 1-7 with 1 = normal and 7 = abnormal.

Table 6. Morphological Analysis of Open Heifers Reproductive Tracts, Trial 2

Treatment	Heifer No.	Comments
+Ralgro	1	Mature tract, infantile, inactive right ovary not cycling, no corpus luteum or corpus albican; small follicles on left ovary.
+Ralgro	2	Normal right ovary; small left ovary with small follicles less than .2 inches in diameter.
+Ralgro	3	Right ovary had two small follicles .3 inches in diameter; left ovary was small with regressing corpus luteum.
+Ralgro	4	Right ovary had cystic follicle; left ovary appeared normal.
+Ralgro	5	Right ovary, normal, 1 follicle .5 inches in diameter and one corpus luteum; left ovary small, inactive.
-Ralgro	1	Right ovary appeared normal with two follicles, one corpus luteum and one corpus albican; left ovary normal size but inactive.

Table 7. Reproductive and Performance Data of Trial 3

Treatment	Heifers exhibiting estrus (%)	Conception rate (%)	ADG	205d wt	ADF	G:F
+Ralgro	94.4	100.0	1.18 ±.14*	286.9 ±12.6*	4.0 ±.9	.30 ±.03
-Ralgro	88.9	88.9	1.04 ±.17*	254.1 ±17.5*	3.9 ±.8	.27 ±.05
Significance	P >.05	P >.05	P <.05	P <.05	P >.05	P >.05

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VEGETATION SURVEY OF ROCKY BRANCH NATURE PRESERVE, CLARK COUNTY, ILLINOIS

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ABSTRACT

The woody vegetation of a 6.5 ha section of the Rocky Branch Nature Preserve, Clark County, Illinois, was surveyed in 1985, and compared to a similar study completed in 1968. In 1985 the stand consisted of 262.6 stems per ha with a basal area of 24.1 sq m per ha as compared to 337.4 stems per ha and a basal area of 22.76 sq m per ha in 1968. White oak has maintained its dominance, while sugar maple moved from fifth to second in importance value exceeding black and red oak. Other species have undergone minor changes in rank. The data indicate that sugar maple increased significantly since the 1968 survey, and as the veteran oaks die it will probably continue to increase in importance.

INTRODUCTION

Rocky Branch Nature Preserve is located six miles northwest of Marshall, Clark County, Illinois. This woodlot represents a remnant of the typical forests associated with the Illinoian till in east-central Illinois, and is located in the Southern Upland Section of the Wabash Border Division (Schwegman 1973). In this section the oak forests contain a mixture of beech, sugar maple, tulip tree, and other tree species typical of the forests to the east of Illinois. Associated with the woodlot are many species not common in this part of Illinois (Stover 1930, Arzeni 1947). Due to this unique flora, the land bordering parts of Rocky Branch Creek was purchased by the Illinois Chapter of The Nature Conservancy and placed under the trusteeship of Eastern Illinois University. The area is now maintained as a natural area for instructional and research purposes. The woody vegetation of the eastern section of

the preserve was surveyed by Hughes and Ebinger (1973), while the western section was surveyed by Ebinger and Parker (1969).

The present study, completed in 1985, was undertaken in the western section of the preserve. This 6.5 ha (16 acre) woodlot is located in the NE ¼, SE ¼ of Section 30, T12N R12W, Clark County, Illinois. Topography varies from nearly level in the western part to highly dissected with gradually sloping to steep sided ravines in the remainder of the area. Sandstone outcrops and a steep hillside overlooking Rocky Branch Creek occur on the northern edge of the area. Overall relief is about 20 m (60 ft) with the high point being 197 m (645 ft) above sea level.

Studies of other woodlots in central Illinois indicate a major shift in species composition over the past 20 years (Ebinger 1986). The major change involves a dramatic increase in the importance of sugar maple, and a corresponding decrease in the importance of the oak species. The present study was undertaken to determine if a similar situation is occurring in this woodlot, since an earlier study of the area is available for comparison (Ebinger and Parker 1969).

MATERIALS AND METHODS

Survey and analysis procedures follow those of Ebinger and Parker (1969). The study area was divided into 21 quadrats 0.25 ha (0.62 acres) in size, and the number, dbh, and species of all trees above 10 cm (4 inches) dbh were recorded for each quadrat. Dead-standing trees were also measured and identified. In each of the 0.25 ha quadrats two nested circular plots were established at four randomly chosen locations. Saplings (2.5-10.0 cm dbh) were tallied on 0.01 ha plots and seedlings (less than 2.5 cm dbh) on 0.001 ha plots. Seedlings were sampled by size classes which were defined as less than 30 cm tall and greater than 30 cm tall but less than 2.5 cm dbh.

Data were summarized by calculation of density (stems/ha), relative density, relative dominance, and importance value (IV) for tree species. The determination of the relative values follows the procedure outlined by McIntosh (1957) and Boggess (1964) in which the IV is the summation of the relative density and relative dominance. Sapling and seedling data were summarized by calculation of density (stems/ha) and frequency. Nomenclature follows Mohlenbrock (1975).

RESULTS AND DISCUSSION

A total of 35 woody species were recorded on the woodlot. Of this total 21 were canopy trees, six were understory trees, and eight were shrubs and vines. Comparison to the 1968 survey (Ebinger and Parker 1969) indicate a decrease in total stand density from 337.4 to 262.6 stems per ha (Table 1). This decline is the result of a decrease in the number of stems of oak and hickory species in the lower diameter classes. White oak alone decreased from 61 stems per ha in 1968 to 19 stems in 1985 in the 1-2 and 2-3 dm diameter classes (Table 1).

Presence of dead-standing stems in the woodlot also suggested that most of the decrease was in the lower diameter classes. Overall, dead-standing individuals averaged 20 stems per ha with a basal area of 7.7 sq m per ha. White oak and hickory species averaged 6.8 and 6.4 dead-standing stems per ha, respectively. Nearly all of

these individuals had a dbh of less than 25 cm. The only species which consistently had dead-standing individuals in the high diameter classes were red and black oaks.

Another major change since the 1968 survey was in the IV ranking of some species. White oak remained the highest ranking in IV, relative density, and relative dominance. Although white oak accounted for more than 1/3 of the IV, it is not well represented in the 1-2 and 2-3 dm diameter classes (Table 1). Also it was not well represented in the seedling and sapling categories. Sugar maple, in contrast, increased from fifth to second in IV, exceeding black and red oaks in importance (Table 1). In addition, sugar maple almost doubled in density and dominated the 1-2 dm diameter class, as well as the seedling and sapling categories (Table 2). The average diameter of this species was only 16.8 cm with a few individuals reaching 40 cm dbh.

The decrease of white oak in the smaller diameter classes and the corresponding increase of sugar maple in these categories, is mostly due to the increased recruitment of saplings of sugar maple into the lower diameter classes. Some of the white oak loss is the result of outgrowth of this species to larger diameter classes. Most, however, appears to be the result of death of many of the smaller diameter white oaks due to natural causes and fire. In the early spring of 1980 a ground fire burned about 1 ha of this section of the woodlot. The fire caused a total top kill of all woody seedlings and saplings, and a few smaller trees, but did not kill any trees with a diameter greater than 15 cm dbh. The results of this fire on the woody understory is discussed by Ebinger (1988).

The importance of black and red oak (third and fourth in IV) was primarily due to their high relative dominance, as indicated by their average diameters of 46.5 and 36.1 cm, respectively. Both species ranked low in seedling and sapling density and frequency and have few stems in the 1-2 dm diameter class (Table 1 & 2).

The hickories have undergone changes in order of their ranking within the woodlot. In 1968, shagbark hickory was ranked highest among the hickories followed by mockernut, bitternut, and pignut. By 1985, mockernut hickory had surpassed the other hickory species in importance followed by shagbark, pignut, and bitternut. Hickory seedlings and saplings, in general, decreased in relative importance from 1968 to 1985 (Table 2) and, except for mockernut hickory, decreased in density (Table 1).

The remaining tree species essentially maintained their minor importance. Black walnut decreased slightly in IV while slippery elm maintained its importance (Table 1). Slippery elm ranked second in seedlings density and frequency, nearly doubling in numbers since 1968. White ash, ranked just below slippery elm, changed little in IV, but decreased in seedlings and saplings density (Table 2).

The future status of oak species in this woods appears to be one of continued importance, at least for the near future. However, due to the small number of individuals of this species group in the smaller diameter classes, the oaks will eventually decrease in importance as the inevitable mortality of the veteran trees continues. To some extent they will be replaced by various species of hickories, however, it is more likely that sugar maple will become the leading dominant. Sugar maple presently dominates the 1-2 dm diameter class and far exceeds all other species in the seedling and sapling density and frequency. The data indicate that sugar maple increased significantly over the past 17 years. Since this species has a high gap-phase-replacement-potential (Runkle, 1984), which allows it to take

advantage of canopy openings that occur when veteran trees die, it will probably continue to increase in importance.

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Table 1. Density by diameter class, density all stems, basal area, relative value, and average diameter for the leading dominants in the western section of the Rocky Branch Nature Preserve, Clark County, Illinois. Density and importance value for the 1968 survey are also given.

Species	Density (stems/ha) by diameter classes (dm)						Density (stems/ha)		Basal Area (sq.m. /ha.)	Relative Values				Av. Diam. (cm)
	1-2	2-3	3-4	4-5	5-6	6+	1985	1968		Rel. Den.	Rel. Dom.	I.V. 1985	I.V. 1968	
White Oak	5.7	13.1	23.4	24.8	14.7	5.7	87.4	113.2	12.4	33.3	51.4	84.7	80.9	40.4
Sugar Maple	37.1	5.1	1.1	1.5	.6	.4	45.8	26.7	1.4	17.5	5.8	23.3	12.9	16.8
Black Oak	1.0	1.5	3.2	4.8	4.4	3.4	18.3	23.7	3.4	6.9	14.0	20.9	20.5	46.5
Red Oak	4.9	3.0	3.2	2.9	3.8	1.7	19.5	25.7	2.5	7.5	10.3	17.8	20.0	36.1
Mockernut	9.5	6.5	2.9	.9	.2	—	20.0	18.8	.9	7.6	4.0	11.6	8.7	22.6
Shagbark	13.7	6.1	1.1	.4	—	—	21.3	34.1	.7	8.1	2.9	11.0	14.0	19.1
Pignut	1.3	1.3	3.8	1.3	.2	—	7.9	13.1	.7	3.0	2.9	5.9	6.0	32.0
Black Walnut	.2	1.5	3.4	1.5	—	—	6.6	10.9	.6	2.5	2.6	5.1	6.2	33.8
Slippery Elm	7.8	1.5	.2	—	—	—	9.5	11.4	.2	3.6	.9	4.5	4.5	16.0
White Ash	4.2	.8	.9	.6	—	—	6.5	7.7	.3	2.5	1.2	3.7	3.2	20.8
Bitternut	2.1	1.7	1.1	.4	—	—	5.3	17.0	.3	2.0	1.2	3.2	8.5	25.1
Beech	1.1	.2	.4	.8	—	.8	3.3	2.7	.4	1.2	1.8	3.0	1.9	35.1
Others[1]	9.7	.9	.6	—	—	—	11.2	32.4	.3	4.3	1.0	5.3	12.7	—
Totals	98.3	43.2	45.3	39.9	23.9	12.0	262.6	337.4	24.1	100.0	100.0	200.0	200.0	—

[1]Includes *Carpinus caroliniana* Walt. (blue beech), *Celtis occidentalis* L. (hackberry), *Cornus florida* L. (flowering dogwood), *Nyssa sylvatica* Marsh. (sour gum), *Ostrya virginiana* (Mill.) K. Koch. (hop hornbeam), *Platanus occidentalis* L. (sycamore), *Populus deltoides* Marsh. (cottonwood), *Prunus serotina* Ehrh. (wild black cherry), *Quercus imbricaria* Michx. (shingle oak), *Sassafras albidum* (Nutt.) Nees. (sassafras), *Tilia americana* L. (basswood), and *Ulmus americana* L. (American elm).

Table 2. Density (stems/ha) and frequency of seedlings and saplings in the western section of the Rocky Branch Nature Preserve, Clark County, Illinois. Seedlings and saplings density for the 1968 survey are also given.

		Seedlings						Saplings		
		Less than 30 cm tall		Greater than 30 cm tall		Total Density		Total Density		
Scientific Name	Common Name	Den.	Freq.	Den.	Freq.	1985	1968	1985	1968	Freq.
Acer saccharum Marsh.	sugar maple	9914	26.2	2207	28.6	12121	11003	418	324	54.8
Ulmus rubra Muhl.	slippery elm	472	14.3	3118	33.3	3590	1700	64	156	16.7
Fraxinus americana L.	white ash	912	17.9	912	22.6	1824	5058	10	40	3.6
Cornus florida L.	fl. dogwood	119	4.8	1030	23.8	1149	1080	148	180	32.1
Carya spp.[1]	hickories	442	—	645	—	1087	1460	109	136	—
Ostrya virginiana K. Koch.	hop hornbeam	148	6.0	235	8.3	383	2970	57	84	16.6
Prunus serotina Ehrh.	black cherry	119	4.8	205	7.1	324	1001	2	5	1.2
Carpinus caroliniana Walt.	blue beech	119	3.6	148	4.8	267	1352	15	54	4.8
Sassafras albidum Nees.	sassafras	89	3.6	175	4.8	264	385	—	—	—
Quercus spp.[2]	oaks	89	—	148	—	237	803	—	17	—
Fagus grandifolia Ehrh.	beech	30	1.2	59	2.4	89	77	5	7	2.4
Juglans nigra L.	black walnut	30	1.2	30	1.2	60	—	—	—	—
Other trees[3]		30	—	119	—	149	304	7	25	—
Vines and shrubs[4]		4030	—	1500	—	5530	8377	—	—	—
Totals		16543	—	10531	—	27074	35570	835	1028	—

[1]Includes *Carya cordiformis* (Wang.) K. Koch. (bitternut), *C. glabra* (Mill.) Sweet. (pignut), *C. ovata* (Mill.) K. Koch. (shagbark), and *C. tomentosa* (mockernut).

[2]Includes *Quercus alba* L. (white oak), *Q. imbricaria* Michx. (shingle oak), *Q. rubra* L. (red oak), and *Q. velutina* Lam. (black oak).

[3]Includes *Celtis occidentalis* L. (hackberry), *Crataegus mollis* (Torr. & Gray) Scheele. (red haw), *Amelanchier arborea* (Michx. f.) Fern. (shadbush), *Morus rubra* L. (red mulberry), *Tilia americana* L. (basswood), and *Ulmus americana* L. (American elm).

[4]Includes *Corylus americana* Walt. (hazelnut), *Hydrangea arborescens* L. (wild hydrangea), *Ribes missouriense* Nutt. (Missouri gooseberry), *Rubus allegheniensis* Porter. (common blackberry), *Sambucus canadensis* L. (elderberry), *Staphylea trifolia* L. (bladdernut), *Toxicodendron radicans* (L.) Kuntze. (poison ivy), and *Viburnum recognitum* Fern. (smooth arrowwood).

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WOODY UNDERSTORY AFTER A SPRING BURN AT THE ROCKY BRANCH NATURE PRESERVE, CLARK COUNTY, ILLINOIS

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ABSTRACT

The woody understory at the Rocky Branch Nature Preserve was surveyed in burned and unburned forested areas. In the unburned areas seedlings average 1.57 individuals per sq m and saplings 0.29 individuals per sq m. In the burned area no saplings are present, but seedlings average 8.73 individuals per sq m. In both areas sugar maple is the most important understory component, accounting for more than 30% of the seedlings and 80% of the saplings in the unburned area, and 75% of the seedlings in the burned area. Very few seedlings and saplings of oak and hickory species occur in the understory. The data indicates that a ground fire will remove most of the sugar maple saplings, and will open the sapling canopy. Sugar maple, however, will continue to dominate in these newly created gaps after a single fire.

INTRODUCTION

Rocky Branch Nature Preserve is a 53 ha (130 acre) woodlot located six miles northwest of Marshall, Clark County, Illinois. This preserve is in the northern part of the Southern Uplands Section of the Wabash Border Natural Division (Schwegman, 1973). In this section the oak forests contain a mixture of beech, sugar maple, tulip tree, and other species typical of the forests to the east of Illinois.

Several vegetation studies have been undertaken in the preserve. The plant associations and a checklist of the vascular plant species were reported by Stover (1930), while Arzeni (1947) prepared a checklist of the bryophytes. Ebinger and

Parker (1969) studied the woody vegetation of the western section of the preserve, the eastern section was surveyed by Hughes and Ebinger (1973), while Hellinga and Ebinger (1970) prepared a checklist of the vascular plants. In 1985 the woody vegetation of the western section was again surveyed (Clapp and Ebinger, 1988). The results of these surveys indicate that the forests in the preserve are undergoing a change in structure and species composition. The major changes involve the explosive increase in sugar maple (*Acer saccharum* Marsh), and a corresponding decrease in the importance of the oak species.

In the original study of the western section of the preserve (Ebinger and Parker, 1969) sugar maple ranked fifth in importance value (IV) while presently it ranks second in IV behind white oak (Clapp and Ebinger, 1988). Other taxa with high IV's include black and red oak along with mockernut, shagbark and pignut hickory. Similar results have been observed in other forests in east-central Illinois (McClain and Ebinger, 1968; Newman and Ebinger, 1985). These findings indicate that sugar maple is replacing oaks and hickories as the dominant forest species in central Illinois (Ebinger, 1986). Runkle (1984) found that this aggressive species is able to rapidly fill tree-fall gaps. Also, this species grows rapidly, even in fairly small gaps, due to its ability to grow and form extensive root systems at low light levels (Logan, 1965).

The present study was undertaken to determine the woody understory composition of a section of this woodlot that had been subjected to a ground fire in 1980, and compare the result to an adjacent portion that had not burned. The results give some indication as to the effect of a single fire on a sugar maple dominated understory.

DESCRIPTION OF THE STUDY AREA

The study area is located in the western most portion of the Rocky Branch Nature Preserve, which consists of a 6.5 ha (16 acre) woodlot located in the NE ¼, SE ¼ of Section 30, T12N, R12W, Clark County, Illinois. The topography of the area varies from a level to gently sloping upland in the western part while the remainder of the area is divided by ravines with gradually sloping sides to steep banks. Ebinger and Parker (1969) divided the woodlot into three vegetation regions based on woody overstory composition: a white oak region which occurs on the relatively flat uplands, a sugar maple region on a steep north-facing hillside, and a mixed hardwood region on the slopes and lowland areas associated with small streams and ravines. The present study was conducted in the white oak region. Here white oak accounts for over 40% of the total IV with 87 stems per ha, while black oak (18.3 stems per ha, IV of 20.9) and hickories (49.2 stems per ha, IV of 28.5) are the most common associates. Also, in this cover type sugar maple is extremely common in the seedling and sapling categories, as well as in the lower diameter classes, averaging 45.8 stems per ha and with an IV of 23.3 (Clapp and Ebinger, 1988).

METHODS AND MATERIALS

Eight 50 m transects were randomly located in the unburned section of the white oak region while four 25 m transects were located in the burned section. Along each transect continuous 1 sq m quadrats were established and all woody

seedlings (less than 2.5 cm dbh) and saplings (2.5-10.0 cm dbh) were counted and identified (Mohlenbrock, 1975). For all seedlings and saplings over 100 cm in height a basal cross section of the stem was removed and the number of annual rings determined. Also, the height (cm) and basal diameter (mm) of all of these individuals was recorded. All woody seedlings were recorded by height class (less than 40 cm tall, 40-100 cm tall, more than 100 cm tall). From this data the density (individuals per sq m) and the frequency was determined for each species.

RESULTS AND DISCUSSION

In the early spring of 1980 a ground fire of unknown origin burned through part of the woodlot at the western edge of the Rocky Branch Nature Preserve. A small part of the mixed hardwood region and less than one-quarter of the white oak region burned. The fire resulted in a total top kill of all woody seedlings, saplings, and a few of the smaller diameter trees, but did not kill any tree with a diameter greater than about 15 cm dbh.

Twelve species of woody seedlings were recorded from the plots in the section of the white oak region that had not burned (Table 1). Of these species, only *Acer saccharum* and *Ulmus rubra* are commonly encountered, both average more than 0.5 seedlings per sq m and with a frequency of 29% or greater. Most of the *A. saccharum* seedlings are small, usually less than 40 cm tall, while the majority of the *U. rubra* seedlings are between 40 and 100 cm in height. The seedlings of the other species encountered are always less than 40 cm tall, and most appear to be one or two year old plants. *Acer saccharum* completely dominates the sapling category in this section of the white oak region (Table 1), averaging 0.25 individuals per sq m. Of the *A. saccharum* individuals over 100 cm tall two distinct size classes are present. A few individuals are found that averaged close to ten years in age, have an average basal diameter of 10 mm, and an average height of 126 cm. The second group exceed 20 years in age, has a diameter greater than 20 mm, and a height greater than 240 cm. This gap in size and age is probably the result of past disturbance in the woods 12 to 15 years ago. This disturbance was probably a ground fire, since old fire scares are present on some of the older saplings and young sugar maple trees.

In the section of the white oak region that burned in 1980, *Acer saccharum* seedlings dominate the understory, accounting for more than 75% of all the individuals recorded (Table 2). Overall, this species averages 6.62 seedlings per sq m with most of the individuals in the less than 40 cm height class. The larger seedlings of this species (over 100 cm height class) are mostly stump sprouts from top killed saplings, are seven years old, average 11.4 mm in diameter at the base, and are less than 2 m tall. The seedlings of all other species are poorly represented, and except for a few individuals of *Ostrya virginiana, Ulmus rubra,* and *Cornus florida,* none reached more than the 100 cm height class (Table 2). All of the oak and hickory seedlings encountered in this region are less than 40 cm tall. No saplings were encountered in the plots in this section of the woodlot.

Though the western section of Rocky Branch Nature Preserve still contains many large oak and hickory trees (Clapp and Ebinger, 1988), the present study indicates that they are not reproducing since few individuals of these species are found in the understory. The present data also suggests that sugar maple is an

aggressive species that will replace the oaks and hickories as these veteran trees die. The data also indicate that a ground fire will remove most of the sugar maple saplings and will open the shrub-sapling canopy. Sugar maple will continue to dominate in these newly created gaps after a single fire.

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Table 1. Density (individuals per sq m) and frequency of seedlings and saplings in the unburned part of the white oak region at the Rocky Branch Nature Preserve, Clark County, Illinois.

Species	Seedlings (less than 2.5 cm dbh) Density	Freq. %	Saplings (2.5-10.0 cm dbh) Density	Freq. %
Acer saccharum Marsh.	0.51	29	0.250	24
Ulmus rubra Muhl.	0.59	33	0.010	1
Quercus alba L.	0.15	12	—	—
Fraxinus americana L.	0.14	14	0.005	1
Carya cordiformis (Wang.) K. Koch.	0.07	7	—	—
Carya glabra (Mill.) Sweet.	0.02	2	—	—
Ostrya virginiana (Mill.) K. Koch.	0.02	1	0.010	1
Carya ovata (Mill.) K. Koch.	0.02	2	0.005	1
Prunus serotina Ehrh.	0.02	2	—	—
Quercus velutina Lam.	0.01	1	—	—
Morus rubra L.	0.01	1	—	—
Cornus florida L.	0.01	1	0.010	1
Totals	1.57		0.290	

Table 2. Density (individuals per sq m) and frequency by diameter class for woody seedlings in the burned area of the white oak region at the Rocky Branch Nature Preserve, Clark County, Illinois.

	Less than 40 cm		40-100 cm		More than 100 cm	
	Den.	Freq. %	Den.	Freq. %	Den.	Freq. %
Acer saccharum Marsh.	4.68	93	1.56	63	0.38	23
Quercus alba L.	0.37	27	—	—	—	—
Quercus velutina Lam.	0.18	13	—	—	—	—
Ostrya virginiana (Mill.) K. Koch.	0.15	12	0.16	13	0.02	2
Prunus serotina Ehrh.	0.10	8	0.05	4	—	—
Morus rubra L.	0.08	7	0.09	7	—	—
Ulmus rubra Muhl.	0.07	6	0.17	9	0.04	4
Cornus florida L.	0.06	4	0.13	7	0.09	3
Sassafras albidum (Nutt.) Nees.	0.05	3	—	—	—	—
Carya cordiformis (Wang.) K. Koch.	0.04	4	—	—	—	—
Staphylea trifolia L.	0.03	3	0.12	5	—	—
Carya glabra (Mill.) Sweet.	0.03	3	—	—	—	—
Fagus grandifolia Ehrh.	0.03	3	0.03	3	—	—
Quercus imbricaria Michx.	0.01	1	—	—	—	—
Totals	5.88		2.32		0.53	

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DIAMETER-HEIGHT-BIOMASS RELATIONSHIPS FOR *QUERCUS* AND *CARYA* IN POSEN WOODS NATURE PRESERVE

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ABSTRACT

Diameter and height were measured on 139 trees of *Quercus stellata*, *Q. velutina*, *Q. alba*, and *Carya* in Posen Woods Nature Preserve, Washington County, Illinois. These data were graphed by species and free-hand curves drawn to obtain an average height at 5 cm diameter intervals; species curves were developed for each of three habitat types. Total tree green weight was obtained for each diameter and height from existing biomass tables. These data were converted to dry weight using a conversion factor that ranged from 0.60 to 0.61 for *Quercus* and from 0.64 to 0.68 for *Carya*. A table listing dry weight (kg) by diameter, height and species for each habitat type is presented.

INTRODUCTION

An increasing demand for wood, escalating costs of wood products and concern about sources of energy have generated considerable interest in measuring tree and forest biomass. Information on biomass can be used in harvesting operations when logs are sold by weight, in site evaluation, and in research on nutrient recycling and ecosystem structure. Such studies often provide data and information that can be used to improve forest management and maintain site quality.

One important aspect of structure is the tree diameter-height-biomass relationship. This relationship can be readily studied in mature forest where there has been no major disturbance to influence tree growth and development. The results of a

study on tree diameter, height and biomass in Posen Woods Nature Preserve are reported in this paper.

THE STUDY AREA

Posen Woods is a 16 ha, relatively undisturbed old growth forest located on the Southern Till Plain region in Washington County, Illinois. The Nature Preserve contains one of the best remaining post oak (*Quercus stellata*) flatwoods in a region where this community type originally may have occurred on 10 percent or more of the land area.

The soil of Posen Woods is derived from loess and has a well-developed claypan or fragipan that restricts drainage particularly on level topography. As the name implies, the post oak flatwoods community, in the past called "post oak flats or hickory flats" (Univ. Ill. 1926), is found primarily on extremely level land surfaces (slope <1%) where the Wynoose soil type occurs. This soil is classed as a fine, montmorillonitic, mesic, Typic Albaqualf, and has a nearly impervious claypan that is extremely hard and brittle when dry. Iron and manganese concretions occurring throughout the profile are the basis for the name "buckshot" soil (Univ. Ill. 1926). In Washington County, the Wynoose soil type occupies 12.2 percent or 17,500 ha (Univ. Ill. 1937). Bluford is a closely related soil type in the Till Plain region (U.S.D.A. 1964, 1972) and the flatwoods community also may have been found on the more level surfaces of this soil.

In Posen Woods, the area of Wynoose soil can be divided into two drainage phases corresponding to two community types, henceforth called habitat types. The *Quercus stellata-Cinna arundinacea* (QUST-CIAR) type is found on a site classed as very poorly-drained. Here, *Quercus stellata* is the single dominant species in the cathedral-like overstory. *Cinna arundinacea* is a conspicuous grass in an understory that has a low density of seedlings, saplings, and shrubs. This type covers an area of approximately 2 ha.

The *Quercus stellata-Carya-Toxicodendron radicans* (QUST-CA-TORA) habitat type is found on the poorly-drained phase of the Wynoose soil. *Quercus stellata, Q. velutina* and *Carya* are common overstory trees, however, there are areas where *Q. velutina* does not occur. The understory is characterized by a dense stratum of *Carya* seedlings and saplings; *Toxicodendron radicans* is a scattered understory shrub; *Cinna* is absent. This community occupies an area of about 8.0 ha.

The *Quercus alba-Quercus velutina-Toxicodendron radicans* (QUAL-QUVE-TORA) habitat type is restricted to the Ave soil type which covers an area of about 6 ha. This soil is moderately well-drained, has a fragipan at a depth of approximately 60 cm and is located on the slopes of shallow drainages; the soil is classed as a fine-silty, mixed, mesic, Typic Fragiudalf. Woody species found in this community include *Quercus rubra, Q. stellata, Carya ovata, C. glabra, C. ovalis, C. tomentosa, Ulmus americana, Juglans nigra* and *Morus rubra.*

METHODS

Diameter (DBH) and height were measured on 27 *Quercus stellata* trees in the QUST-CIAR habitat type, 25 *Quercus stellata* trees in the QUST-CA-TORA type,

and 30 *Quercus alba* trees in the QUAL-QUVE-TORA type; 26 *Quercus velutina* trees and 31 *Carya* trees were measured in the QUST-CA-TORA and QUAL-QUVE-TORA types. For each species, measured trees ranged in diameter from approximately 15 cm to the maximum found in Posen Woods. Data for each species were plotted on graph paper, free-hand curves drawn, and an average height obtained at 5 cm diameter intervals beginning with a 15 cm diameter (*i.e.*, 15, 20, 25 cm, etc.). Total stem green (wet) weight for stem diameter and average height by species were obtained from tables developed by Myers, Polak, Raisanen, Schlesinger, and Stortz (1979). These data were converted to total stem dry weight based on the proportion of wet to dry weight of trees studied by the Tennessee Valley Authority (1972, 1978) and by Dr. H.V. Wiant (West Virginia University, Unpublished data). Conversion values ranged from 0.60 to 0.61 for *Quercus* and from 0.64 to 0.68 for *Carya* depending on diameter and height.

RESULTS AND DISCUSSION

The diameter-height relationship for *Quercus stellata* on the QUST-CA-TORA habitat type is shown in Figure 1. The data show that height increases with diameter but at a slowly decreasing rate up to a diameter of approximately 50 cm. Thereafter, tree height appears to decline slightly after reaching a maximum height of 26 m. The reduction in total height probably was caused by the development of the largest, and presumably oldest, trees in more open (high light) conditions which permitted an increase in lateral growth accompanied by a reduced height growth. Trees smaller than 50 cm probably developed under more dense forest conditions.

In contrast, height growth ceases early and maximum tree height is only 22 or 23 m in the QUST-CIAR habitat type (Fig. 2). No apparent height growth occurs on trees larger than 30 cm. Several interacting causes may be cited for the limited height growth on this habitat type. A shallow claypan, lack of topographic relief and distance from a drainage system make the soil very poorly drained in the spring. Limited root distribution within the pan and low amounts of rainfall later in the growing season combine to make this soil moderately to extremely droughty by mid-summer. It is suggested that *Quercus stellata* is more tolerant of these seasonal soil moisture extremes than other *Quercus* and *Carya* species; hence, it forms a nearly pure stand although its growth rate is reduced compared to that of stems on the QUST-CA-TORA habitat type. Also, the QUST-CA-TORA type, which surrounds the QUST-CIAR type, is located closer to stream drainages and may be better drained in the spring when most growth occurs.

Another difference in the soils of the two habitat types is the penetrability of the subsurface horizons. While additional study is needed to evaluate the possible implications of this factor, observations indicate that a soil probe does not easily penetrate beyond depths of 15 cm and 20 cm in the QUST-CIAR and QUST-CA-TORA habitat types, respectively.

In contrast to the variation in the diameter-height relationship of *Quercus stellata* in two habitat types, *Quercus velutina* has a consistent pattern in both the QUST-CA-TORA and QUAL-QUVE-TORA habitat types (Fig. 3). It appears that a maximum height of approximately 27 m is reached at a diameter of 60 to 65 cm. Thereafter, height appears to remain constant.

The pattern for *Quercus alba* on the QUAL-QUVE-TORA habitat type (Fig. 4) is similar to that for *Quercus velutina*. For diameters less than 30 cm, *Q. velutina* stems have slightly greater heights. Beyond 55 cm, *Q. alba* has a greater height for a given diameter. Height continues to increase with diameter up to 75 cm; maximum height on the QUAL-QUVE-TORA habitat type probably is near 30 m with diameters of approximately 85 to 90 cm. This habitat type is found primarily on the Ava soil type where a fragipan at 60 cm is sufficiently deep to allow for adequate water storage and good to excellent tree growth.

The density of individual *Carya* species is low, but collectively, the species are a substantial component of the QUST-CA-TORA and QUAL-QUVE-TORA types. Data from all species were used to develop a single curve because differences between individual curves were small and low numbers of data points prevented the development of reliable curves.

The curve for the various species of *Carya* (Fig. 5) shows that they have a greater height for a given diameter than any *Quercus* species. Its maximum height appears to be near 30 m, about the same as that of *Quercus alba*. However, this height is reached when the diameter is only 60 to 70 cm, while in *Q. alba* stems, the diameter is likely to be in the range of 85 to 90 cm. The result is that *Carya* would tend to have a greater biomass at a given diameter than would *Quercus*.

Examining the diameter-height relationships in the context of age provides a different perspective. While the diameter-height curves are similar for several of the species, their growth rates differ appreciably. Data for *Carya* in the QUST-CA-TORA and QUAL-QUVE-TORA habitat types show that it is taller for a given diameter than *Quercus stellata*, *Quercus alba*, and *Quercus velutina*, although maximum height is likely to be the same as *Q. alba* (30 m). These data could be interpreted to indicate that *Carya* has a faster volume growth than do *Q. alba* or *Q. velutina*; however, these data are misleading. Tree cores show that both *Carya* and *Quercus* stems were established between 1845 and 1855. The largest *Q. alba* and *Q. velutina* are now 60 to 75 cm in diameter while the largest *Carya* are only 50 to 60 cm. *Quercus stellata* stems in the QUST-CA-TORA habitat type have about the same diameter range as *Carya*, but on the QUST-CIAR type, *Q. stellata* are 5 to 10 cm smaller.

Dry weight biomass (kg) estimates by diameter and average height for *Quercus alba*, *Quercus velutina*, and *Carya* and for *Quercus stellata* on two habitat types are listed in Table 1. These data may be converted to wet weight by multiplying by a factor of 1.64 for *Quercus* and 1.56 for *Carya*.

The average height for a given diameter obtained from the curves show that the trees of Posen Woods are in the middle of the height range delineated by Myers et al. (1979) although their data were collected in the unglaciated Shawnee Hills region of southern Illinois. While the data on diameter-height-biomass relationships presented here will be used to study the productivity of the community on each habitat type in Posen Woods, they also may be applicable to other forests in Illinois.

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Table 1. Average height and dry weight by diameter for *Quercus stellata*, *Quercus velutina*, *Carya* and *Quercus alba* in three habitat types in Posen Woods Nature Preserve. Weight is rounded off to the nearest kilogram.

	QUST-CIAR		QUST-CA-TORA		QUST-CA-TORA & QUAL-QUVE-TORA				QUAL-QUVE-TORA	
	Quercus stellata		*Quercus stellata*		*Quercus velutina*		*Carya species*		*Quercus alba*	
DBH (cm)	Ht. (m)	Wt. (kg)	Ht. (m)	Wt. (kg)	Ht. (m)	Wt. (kg)	Ht. (m)	Wt. (kg)	Ht. (m)	Wt. (kg)
15	12.2	95	15.5	96	13.0	76	10.5	95	11.5	92
20	15.8	204	17.7	206	15.7	174	14.5	254	14.5	196
25	19.2	367	19.6	371	18.0	324	18.5	447	17.0	346
30	21.5	571	21.4	571	19.8	511	21.5	753	19.4	554
35	22.7	858	23.3	862	21.4	806	24.0	1050	21.5	830
40	23.0	1159	24.2	1189	23.0	1131	26.0	1451	22.8	1159
45	23.2	1506	25.8	1581	24.2	1529	27.5	1850	24.3	1545
50	23.2	1904	26.2	2020	25.3	2008	28.5	2350	25.4	1998
55	23.2	2353	25.0	2440	26.2	2601	29.5	2809	26.5	2526
60			21.6	2767	26.7	3109	30.0	3300	27.3	3130
65					26.8	3699			28.2	3818
70					26.7	4289			28.9	4500
75					26.5	4500			29.5	5300

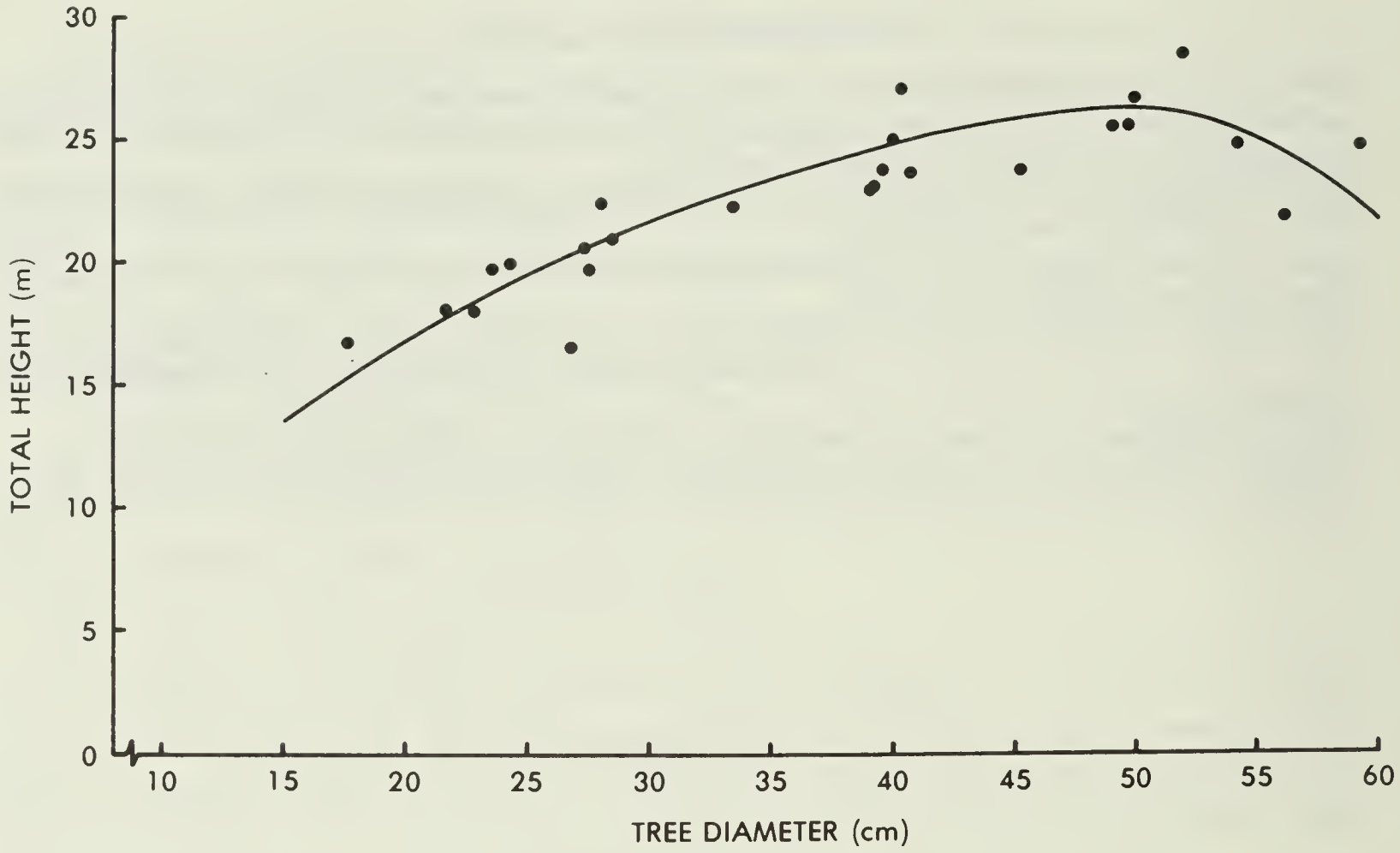

Figure 1. Diameter-height relationship for *Quercus stellata* in the QUST-CA-TORA habitat type in Posen Woods Nature Preserve.

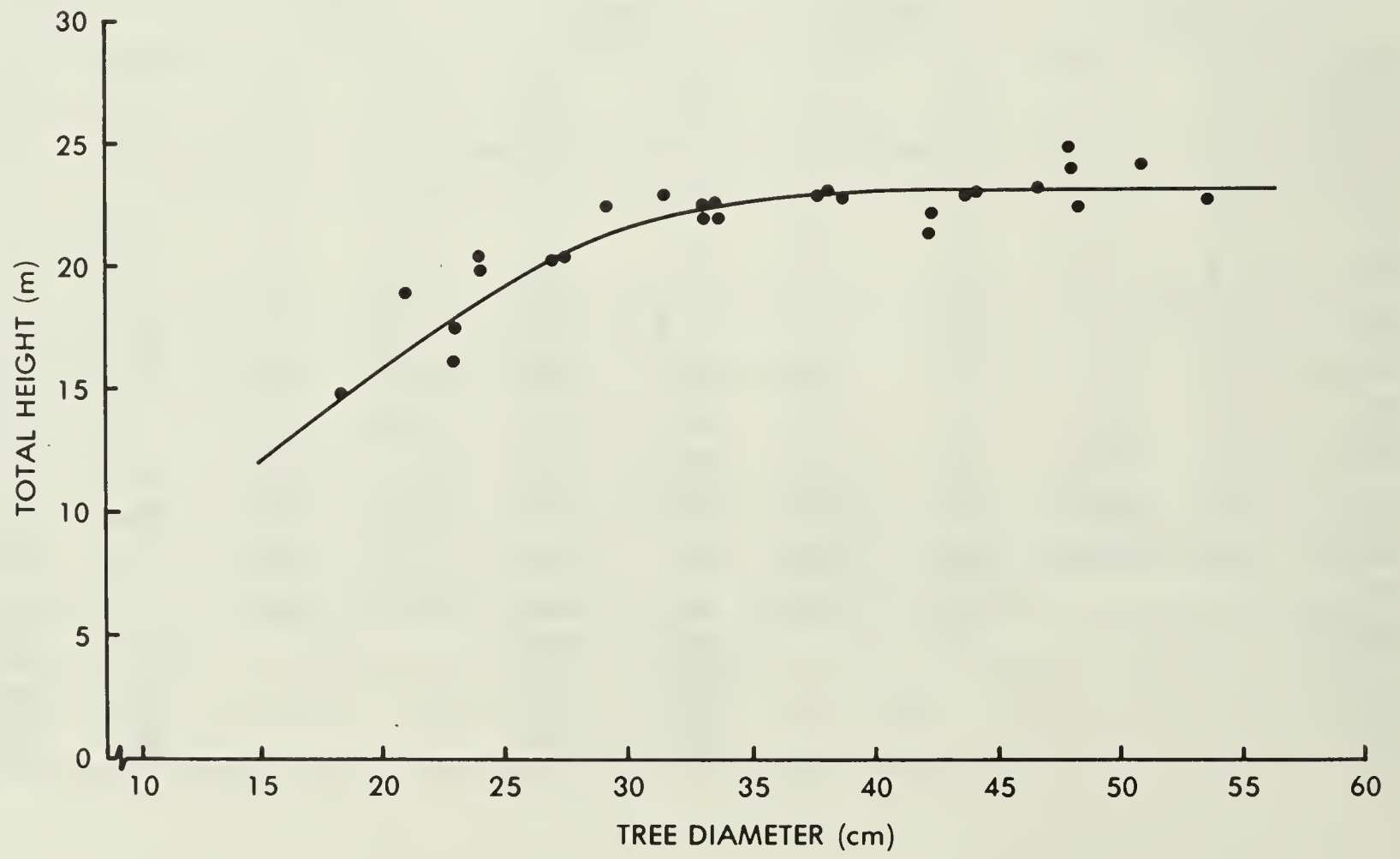

Figure 2. Diameter-height relationship for *Quercus stellata* in the QUST-CIAR habitat type in Posen Woods Nature Preserve.

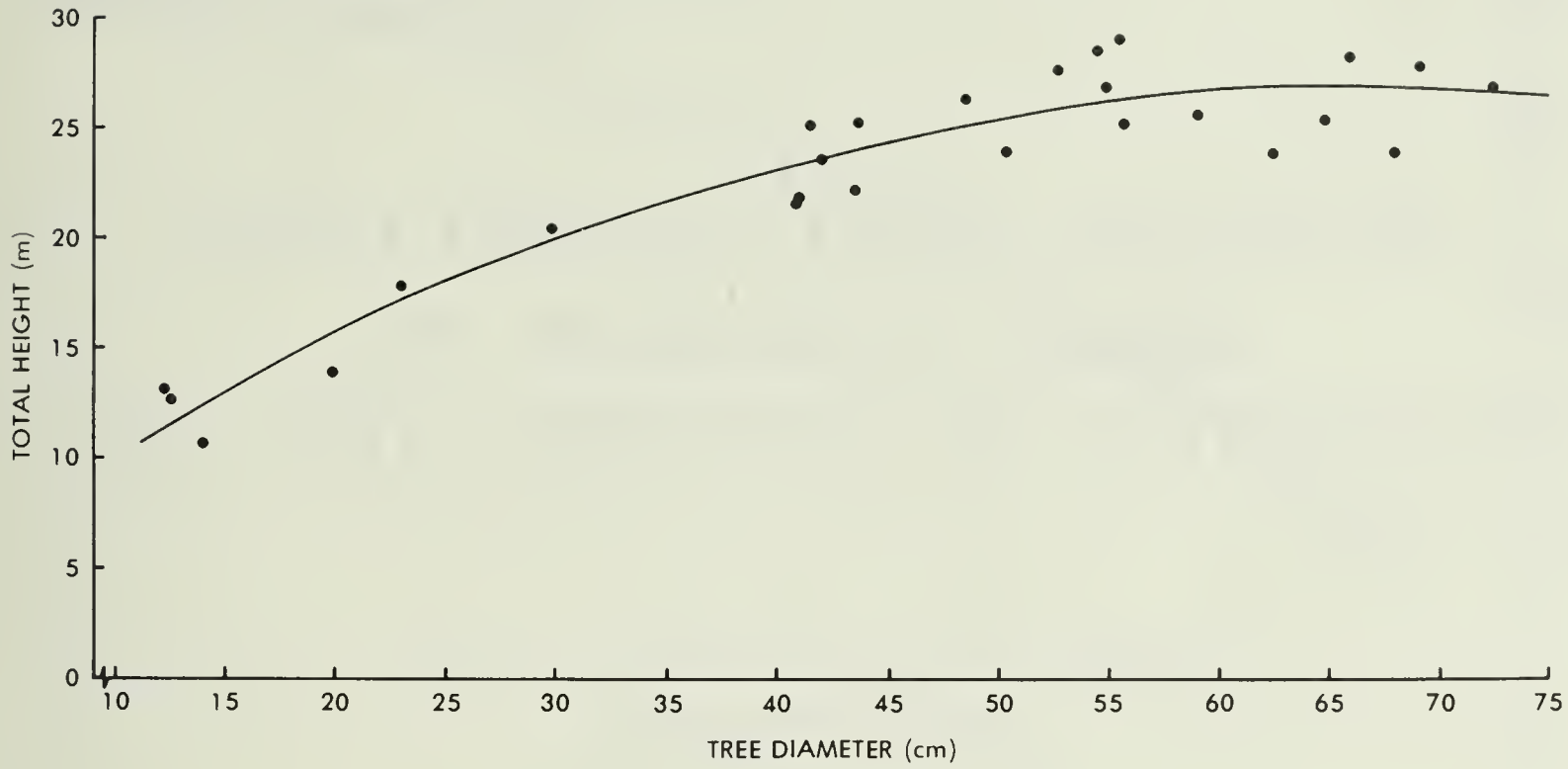

Figure 3. Diameter-height relationship for *Quercus velutina* in Posen Woods Nature Preserve.

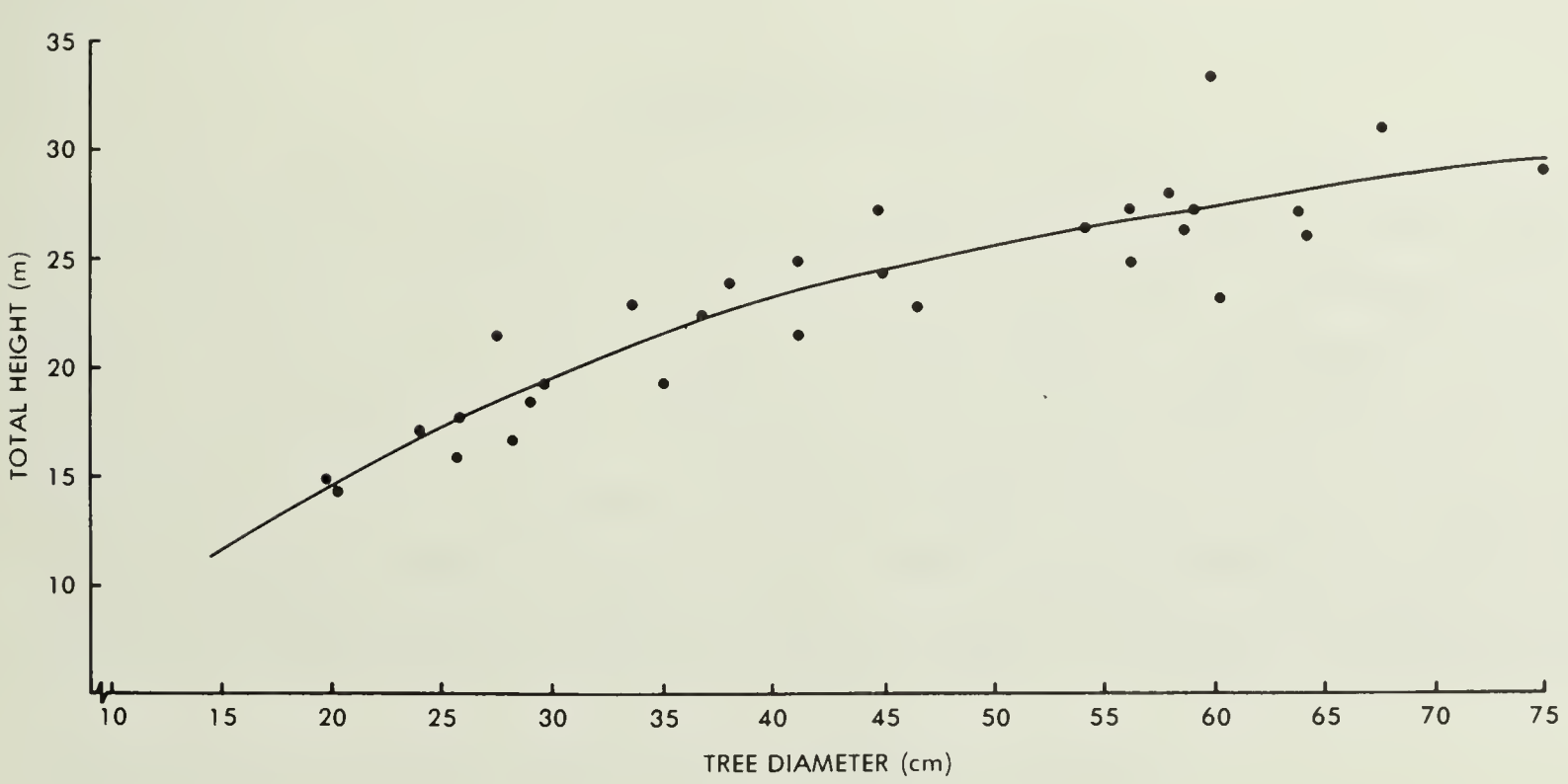

Figure 4. Diameter-height relationship for *Quercus alba* in Posen Woods Nature Preserve.

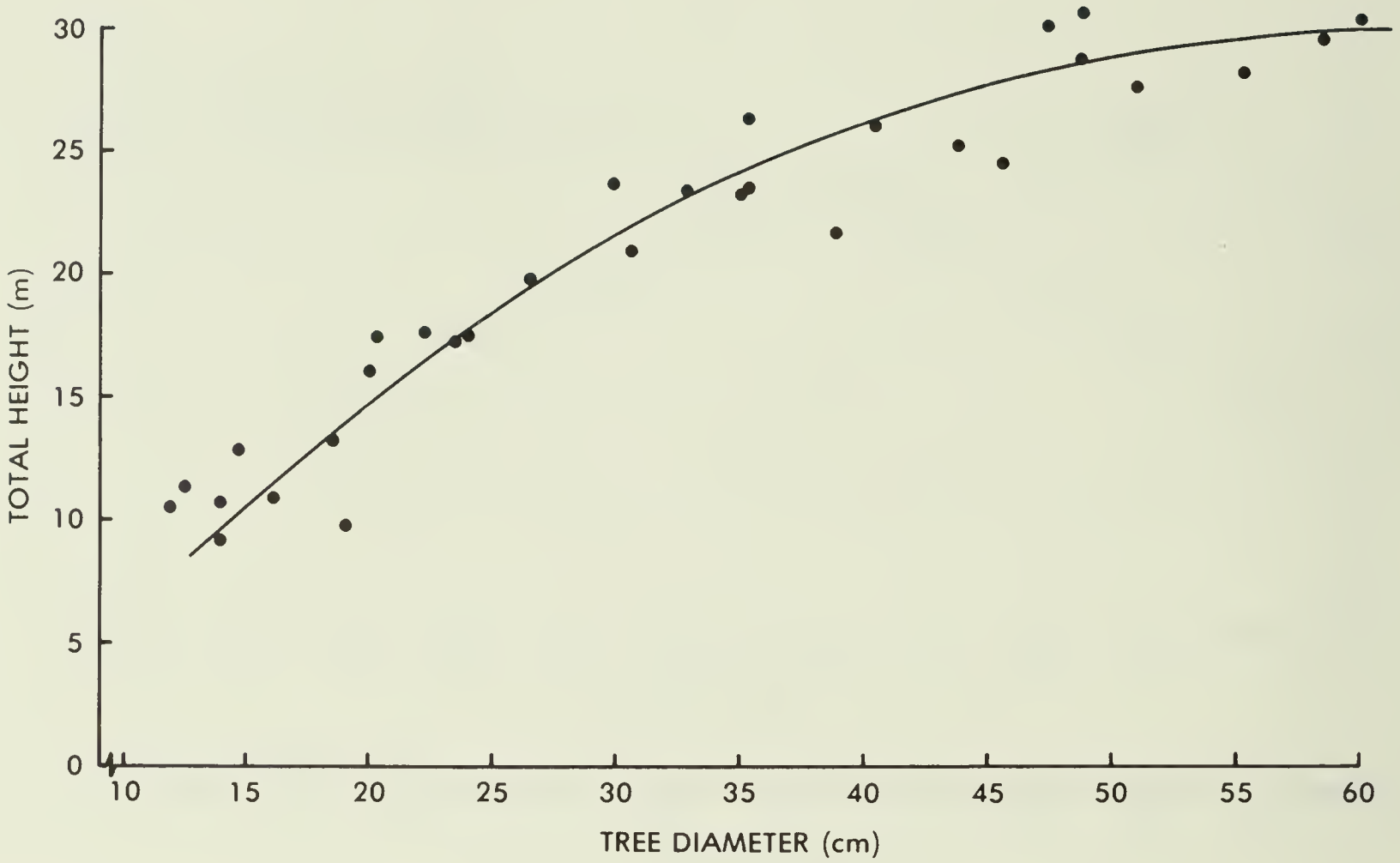

Figure 5. Diameter-height relationship for *Carya* in Posen Woods Nature Preserve.

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NONCOMPETITIVE EFFECTS OF MORNING GLORY ON THE GROWTH OF SOYBEANS

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ABSTRACT

Soybean fields with a significant morning glory (*Ipomea lacunosa* L.) weed infestation often show a marked reduction in yield. These reductions are often attributed to competition for nutrients, water and sunlight, but noncompetitive phytotoxins contained within morning glory plants may also adversely affect soybean yields. A series of studies were performed which identify morning glory leaf leachate and root exudate as significantly reducing growth of soybean (*Glycine max* (L.) Merrill) plants. In addition, ground shoot and root extracts significantly reduced germination of soybean seed.

INTRODUCTION

Morning glory (*Ipomoea hederacea* (L.) Jacq. and *l. purpurea* (L.) Roth.) has been identified in a number of field experiements (Oliver and Frans, 1976; Wilson and Cole, 1966) to have an adverse effect on the growth and development of soybean (*Glycine max* (L.) Merrill) plants. Field experiments such as these measure the total competitive and noncompetitive effects a weed has on a crop. Resulting yield reductions are commonly attributed to competition for water, nutrients and sunlight between the crop species and the weed. In certain situations, noncompetitive (allelopathic) factors should also be considered to more fully explain the eco-physiological situation. Allelopathy is a term describing a plant which exudes phytotoxic chemicals into the environment which can inhibit the growth and

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development of other species (Muller, 1966). In ecological situations, a particular species which is able to inhibit the growth and development of another species would have a definite selective advantage over that species.

Plant phytotoxins can be either volatile or water soluble in nature. Volatile phytotoxins from certain shrubs have been shown to have an adverse effect on annual grasses and forbes in drier habitats (Muller, 1965), while water soluble phytotoxins are more prominent in wetter habitats (Morgan and Tukey, 1964).

Water soluble phytotoxins commonly are released into the environment through leachates from leaves (Rassmussen and Rice, 1971), exudates from roots (Bell and Koeppe, 1972), and accumulated organic matter (Abdul-Wahad and Rice, 1967). Organic matter is not always directly phytotoxic, but first must be decomposed by an intermediate microorganism (Patrick, 1955).

In the present study, techniques were developed to determine whether morning glory emits phytotoxins which have an effect on the germination and growth of soybeans. The sources of morning glory phytotoxins to be investigated include organic matter, leaf leachate and root exudates.

MATERIALS AND METHODS

All plants were grown under greenhouse conditions in 15 cm plastic pots filled with clay loam soil. The photoperiod was extended for morning glory (*Ipomoea lacunosa* L.) to 13 hours with a 40 watt Duro-lite, Vita-lite fluorescent light. The average daily temperature was 20° C.

SEED GERMINATION EXPERIMENT — The extracts were prepared by taking shoot parts (all material 1 cm above highest root) and roots of six-week-old morning glory plants and pulverizing each portion in a Waring blender at a concentration of 50 g/l of deionized water for 90 seconds. The respective extracts were then stirred for four hours before filtering through Whatman's No. 1 filter paper. One 25 ml portion of each extract was immediately tested in separate petri plates containing 55 soybean seeds on absorbent toweling. In conjunction, a deionized water control was similarly constructed. The remaining extracts were allowed to stand for one week in dilution tubes at 25° C before testing as above. All soybean seeds were germinated in an incubator set at 24° C for 72 hours before weighing radicles. Three replications were conducted.

LEAF LEACHATE EXPERIMENT — The shoots of 60 three-week-old morning glory plants were submerged in one liter of water for one hour. Twenty-five pots containing one one-week-old soybean plant were watered with 40 ml of the leachate when the soil was visually dry (approximately every three days). After five weeks of treatment, the shoots, roots and root nodules were harvested and air dried for three days before weighing. A control was run under similar conditions with the omission of the morning glory plants.

ROOT EXUDATION EXPERIMENT — Twenty-five pots containing two two-week-old morning glory plants were watered until enough excess water drained out to saturate the soil of 25 pots containing one one-week-old soybean plant when the soil was visually dry (approximately every three days). After five weeks of treatment, the shoots, roots and root nodules were harvested and air dried for three days before weighing. A control was run under similar conditions with the omission of the morning glory plants.

RESULTS AND DISCUSSION

Studies involving adverse effects of weed infestations in a crop typically do not describe the nature of this plant-plant interaction (Oliver and Frans, 1976; Wilson and Cole, 1966). Although competitive factors are predominant in most situations, noncompetitive factors may contribute to reductions in growth and development of a crop plant. In order to understand these interactions, the crop species must be grown separately from the weed to eliminate any competitive effects, and experimental techniques should identify whether microbes actually create the phytotoxins from plant material and their possible role in degradation.

The seed germination experiment was designed as both a bioassay to determine whether phytotoxins exist in dried morning glory plants and to emulate a possible field condition in which phytotoxins contained in morning glory organic material may inhibit the germination of soybean seed. The results of this experiment (Fig. 1) suggest that shoot extract from five-week plants significantly reduced germination by 11% and radicle weight by 17%, while root extracts significantly reduced germination 11% and radicle weight by 13% in comparison to the control. In contrast, no significant difference for either parameter was noted for extracts that were allowed to stand for one week when compared with the control.

The results suggest that phytotoxins are present in both the shoots and roots of morning glory in approximately the same concentration, but these phytotoxins likely auto-decompose or bacteria or fungi degrade the phytotoxin. Attempts have been made (Bendall, 1975) to control the effects of microbial action from a standpoint that microbes actually produce toxins (Norstadt and McCalla, 1963; Patrick, 1955) from plant material, but the technique utilized in this present study suggests that microbes can decompose the phytotoxins if the extracts are allowed to stand. This technique also minimizes experimental error introduced by physiological drought, since week-old extract, minus the phytotoxin, did not affect any of the parameters measured when compared with the control. Changes in pH could also influence results, but the pH for all extracts was found to be neutral.

Based on the results of this experiment, morning glory organic matter does contain phytotoxins, but these toxins would likely decompose in the soil and not affect germination of soybean seeds under field conditions. These results do not preclude the possible deleterious effects of phytotoxins that are leached from leaves and roots of living morning glory. The next two experiments investigate the role leaf leachates and root exudates have on soybean growth.

Morning glory is a climbing vine that grows intimately among soybean plants. Phytotoxins contained within the leaves of morning glory may leach into the soil during rain and are subsequently taken up by soybean plants. Results of the leaf leachate experiment (Fig. 2) reflect a significant decrease in soybean root weight (40%) and nodule weight (23%) in comparison to the control. No significant difference was noted in shoot weight. These results suggest that phytotoxins contained within leaves of morning glory are capable of leaching and have an adverse effect on at least two of the parameters measured.

Finally, root exudates have also been implicated in containing phytotoxins (Fay and Duke, 1977; Friedman and Horowitz, 1971) in a number of species. A drainage-type watering apparatus was utilized in this study to examine possible phytotoxic effects of root exudates (Bell and Koeppe, 1972). Results (Fig. 3) reflect

a significant decrease in soybean root weight (22%), shoot weight (14%) and nodule weight (31%) in comparison to the control. Results suggest that phytotoxins are exuded from roots of morning glory and have an adverse effect on all parameters measured.

In conclusion, morning glory leaf leachate and root exudate are likely to contain phytotoxins which have an inhibitory effect on the growth of soybean plants. These phytotoxins contained in living morning glory plants may inhibit growth of soybean plants under field conditions, but further studies need to be conducted to substantiate this. Additional studies include the possible role of microbes in degradation of the phytotoxins contained in the organic matter, and the possible effect these phytotoxins have on the *Rhizobium* contained within the nodules.

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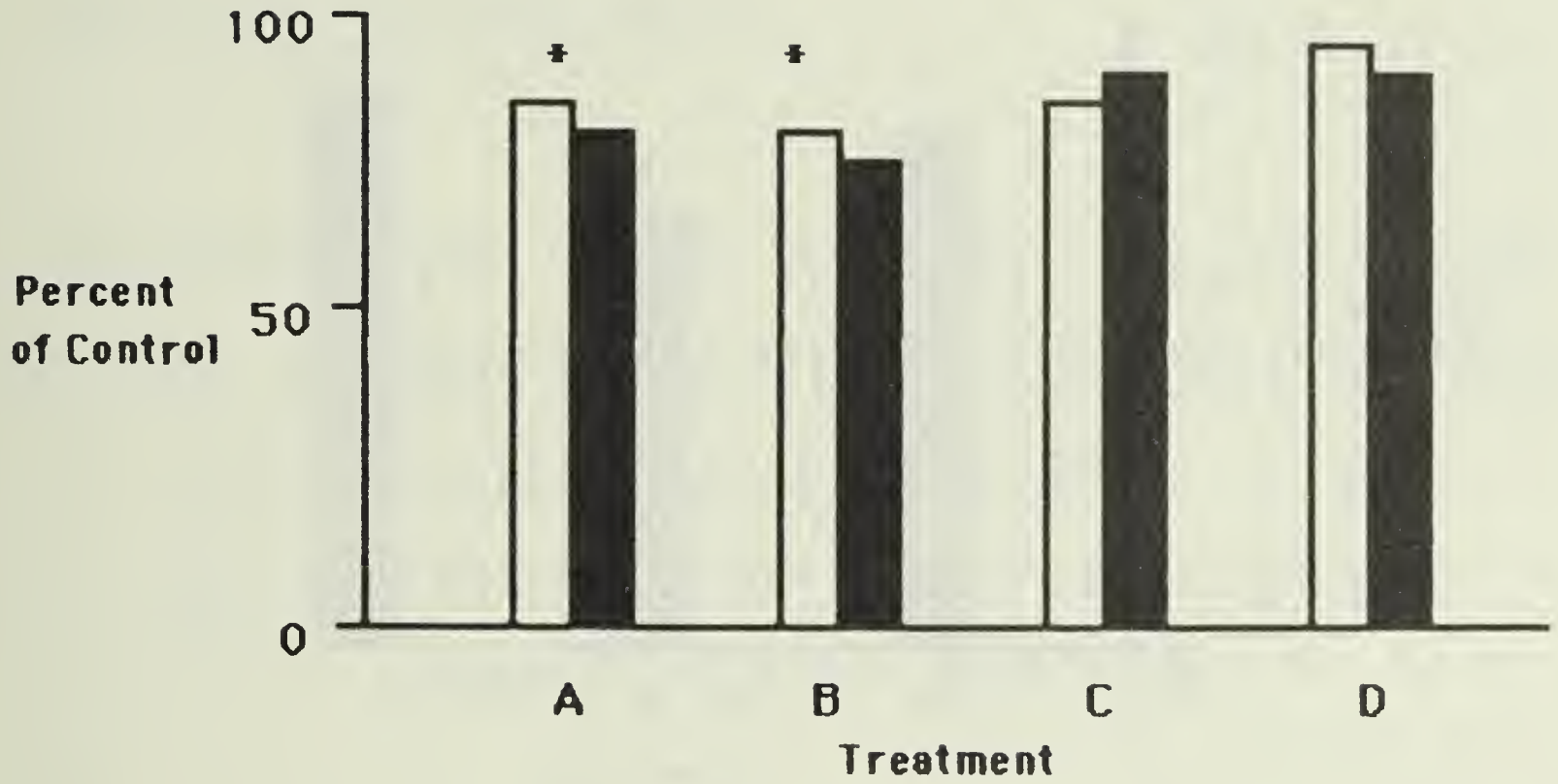

Figure 1. Phytotoxic effects of morning glory root and shoot extracts on soybean germination (white bars) and radicle weight (black bars). (A) root extract; (B) shoot extract; (C) one week-old root extract; (D) one-week-old shoot extract. * Significant difference at P = .05.

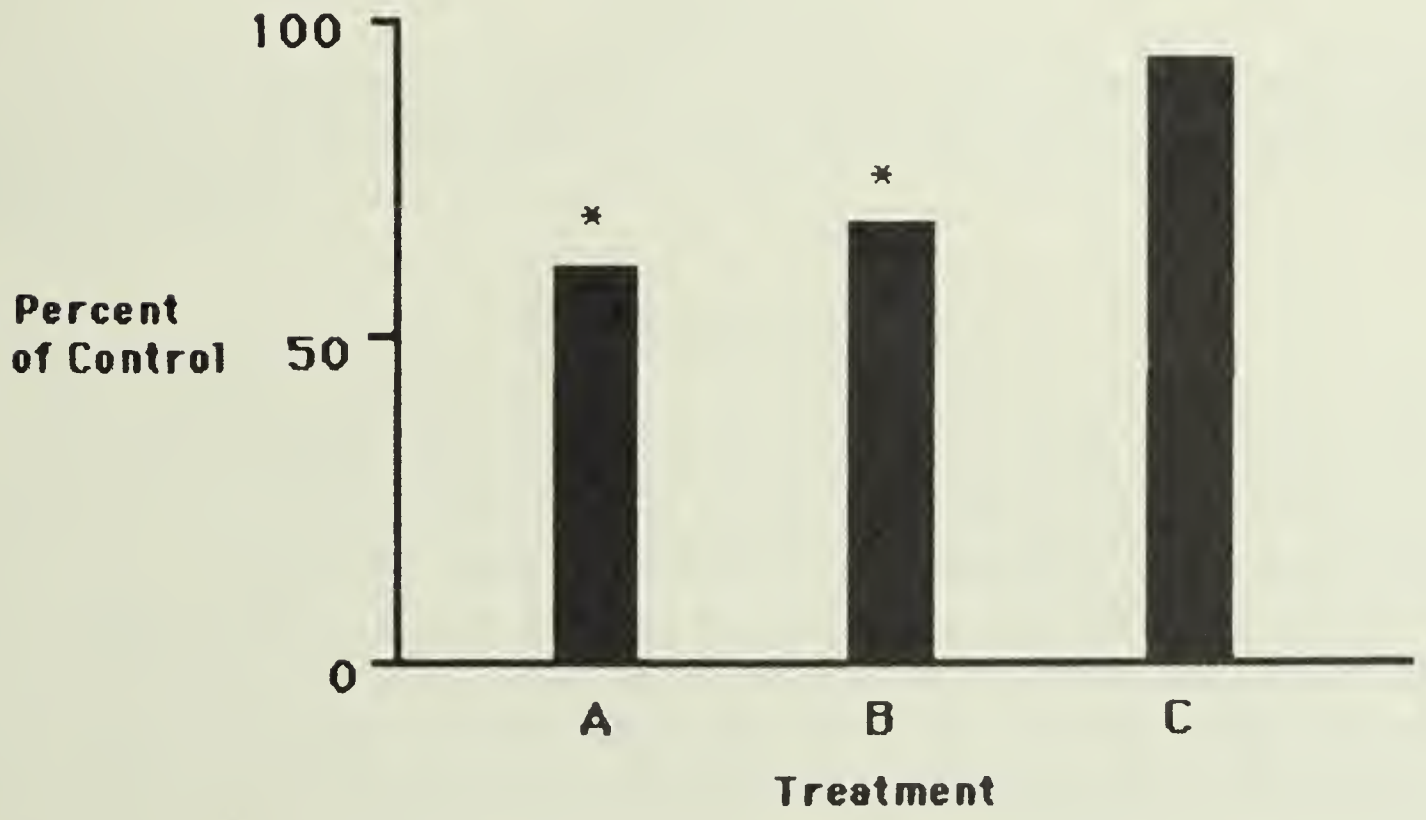

Figure 2. Phytotoxic effects of morning glory leaf leachate on soybean. (A) dry weight of roots; (B) dry weight of root nodules; (C) dry weight of shoot parts. * Significant difference at P = .05.

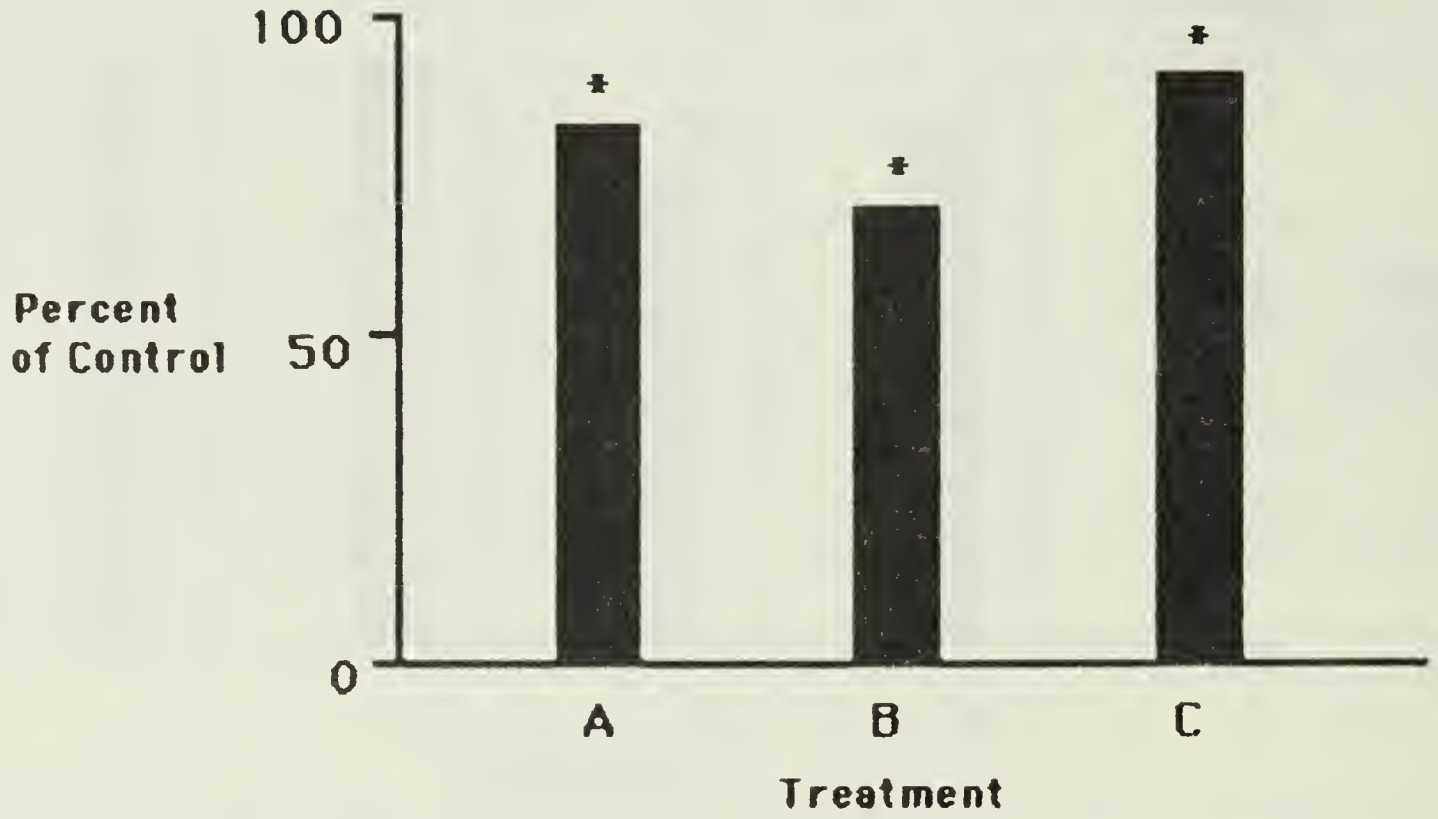

Figure 3. Phytotoxic effects of morning glory root exudations on soybean. (A) dry weight of roots; (B) dry weight of root nodules; (C) dry weight of shoot parts. *Significant difference at P = .05.

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NOTES ON THE ALGAL FLORA OF CASS, MORGAN AND PIKE COUNTIES (ILLINOIS), INCLUDING THE BOUNDARY WATERS OF THE MISSISSIPPI RIVER

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ABSTRACT

Two hundred fifty-four species and varieties of algae, including 110 previously unrecorded taxa, are reported in an annotated listing from Cass, Morgan and Pike Counties (Illinois).

INTRODUCTION

The algal flora of Cass, Morgan and Pike Counties is poorly known with only 24, 5 and 12 published records, respectively (Britton, 1944). Although annotated catalogues (Dillard et al., 1963; Dillard and Tindall, 1973; Grady, 1974; Lipsey, 1976; Richer et al., 1964; Weik, 1966; Wunderlin, 1971), checklists (Dillard and Mohlenbrock, 1962; Jones and Grady, 1980; Kothandaraman et al., 1977; Lipsey, 1975, 1980; Wunderlin and Wunderlin, 1968), and notes on new or interesting algae (Ebinger and Vogel, 1977; Lipsey, 1978, 1985; Mohlenbrock and Dillard, 1963; Stotler, 1968; Weik, 1977, 1982; Weik and Mohlenbrock, 1963; Williams and Tindall, 1975) have appeared sporadically during the last four decades, information on the algae of west-central Illinois is generally lacking in the literature.

The present paper treats 254 species and varieties of algae observed in 51 plankton collections obtained from 12 lotic habitats, including the boundary waters

of the Mississippi River. These current records together with those acknowledged earlier (Britton, 1944) now comprise a list of 51 taxa for Cass County, 25 taxa for Morgan County, and 239 taxa for Pike County. Included are reports for 110 taxa previously unrecorded from Illinois.

COLLECTION LOCALES

1. *Bay Creek* — New Salem Township, Section 34, Pike County. Specific Conductance = 344.5 *u*mhos/cm; pH = 7.6.
2. *Beebe Creek* — Barry Township, Section 16, Pike County. Specific Conductance = 374.5 *u*mhos/cm; pH = 7.5.
3. *Blue Creek* — Griggsville Township, Section 32, Pike County. Specific Conductance = 518.6 *u*mhos/cm; pH = 7.8.
4. *Hadley Creek* — Barry Township, Section 14, Pike County. Specific Conductance = 359.2 *u*mhos/cm; pH = 7.6.
5. *Indian Creek* — Meredosia National Wildlife Refuse, ¼ mile west of U.S. Route 67, Cass County. Specific Conductance = 580.0 *u*mhos/cm; pH = 8.0.
6. *Kise Creek* — Hadley Township, Section 26, Pike County. Specific Conductance = 359.6 *u*mhos/cm; pH = 7.8.
7. *McCraney Creek* — Kinderhook Township, Section 1, Pike County. Specific Conductance = 437.6 *u*mhos/cm; pH = 7.6.
8. *Mississippi River* — at river miles 288.5, 293 and 297.3 along the Pike County border. Specific Conductance = 325.0 *u*mhos/cm; pH = 7.8.
9. *New Pankey Pond Ditch* — Meredosia National Wildlife Refuge, ½ mile east of U.S. Route 67, Cass County. Specific Conductance = 500.0 *u*mhos/cm; pH = 8.0.
10. *Pigeon Creek* — Kinderhook Township, Sections 8 and 18, Pike County. Specific Conductance = 435.5 *u*mhos/cm; pH = 7.8.
11. *Unnamed ditch near Meredosia Lake* — Meredosia National Wildlife Refuge, 1 mile west of U.S. Route 67, Cass County. Specific Conductance = 510.0 *u*mhos/cm; pH = 7.4.
12. *Willow Creek* — Meredosia National Wildlife Refuge, 2 miles west of U.S. Route 67 near Meredosia Lake, Morgan County. Specific Conductance = 600.0 *u*mhos/cm; pH = 7.5.

ANNOTATED CATALOGUE

Nomenclature in the listing follows that of Fott (1968), Håkansson and Stoermer (1984a, b), Huber-Pestalozzi (1974), Komárek and Fott (1983), Mohlenbrock and Dillard (1963), Patrick and Reimer (1966, 1975), Prescott (1962), Prescott et al. (1982), Stoermer and Håkansson (1984), Taft and Taft (1971), Tynni (1980), Walton (1915), and Weik and Mohlenbrock (1963). Entries preceded by an asterisk represent new Illinois records. In each citation the county in which the species was discovered is indicated in upper case followed by the collection locale(s), month of sampling, and year of procurement. The arrangement of the taxa is according to Smith (1950). Soft algae samples and permanent diatom slides have been deposited in the Chicago Field Museum and Philadelphia Academy of Science (Diatom Herbarium), respectively.

CHLOROPHYTA

Chlorophyceae

Volvocales

**Carteria globulosa* Pasch. PIKE: Kiser Creek, April, 1985.

**C. klebsii* (Dang.) Francé *emend.* Troitz. PIKE: McCraney Creek, May, 1985; Mississippi River at mile 293, August, 1985.

Chlamydomonas globosa Snow. PIKE: Bay Creek, April, 1985; Beebe Creek, April, 1985; Hadley Creek, April, 1985.

C snowii Printz. PIKE: Kiser Creek, April, 1985.

**Chlorobrachis gracillima* Korš. PIKE: Blue Creek, April, 1985.

Eudorina elegans Ehrenb. PIKE: Mississippi River at mile 288.5, August, 1985.

Pandorina morum (Müll.) Bory. PIKE: Bay Creek, April, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, 1985.

**Pyrobotrys gracilis* Korš. PIKE: Blue Creek, April, 1985.

Tetrasporales

Elakatothrix viridis (Snow) Printz. PIKE: Mississippi river at miles 288.5 and 297.3, August, 1985.

Gloeocystis gigas (Kütz.) Lag. MORGAN: Willow Creek, June, 1982.

Sphaerocystis schroeteri Chod. MORGAN: Willow Creek, June, 1982. PIKE: McCraney Creek, May, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, 1985.

Chlorococcales

Actinastrum hantzschii var. *fluviatile* Schröder. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, 1985.

Ankistrodesmus falcatus (Corda) Ralfs. PIKE: Blue Creek, April, 1985; Hadley Creek, April, 1985; Mississippi River at miles 288.5 and 297.3, August, 1985.

**Chlorolobium braunii* (Näg.) Kom. CASS: Indian Creek, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Blue Creek, April, 1985; Mississippi River at mile 297.3, August, 1985.

**Closteriopsis acicularis* (G.M. Smith) Belch. & Swale. PIKE: Bay Creek, April, 1985; Pigeon Creek, May, 1985.

Coelastrum microporum Näg. CASS: Indian Creek, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: McCraney Creek, May, 1985; Mississippi River at miles 288.5 and 297.3, August, 1985; Pigeon Creek, May, 1985.

Dictyosphaerium ehrenbergianum Näg. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

D. pulchellum Wood. PIKE: McCraney Creek, May, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

Franceia droescheri (Lemm.) G.M. Smith. PIKE: Mississippi River at mile 288.5, August, 1985.

Golenkinia radiata (Chod.) Wille. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

**Kirchneriella contorta* (Schmidle) Bohlin. CASS: Indian Creek, June, 1982.

**Lagerheimia ciliata* (Lag.) Chod. PIKE: Mississippi River at mile 288.5, August, 1985.

**L. genevensis* (Chod.) PIKE: Mississippi River at mile 297.3, August, 1985.

**L. wratislaviensis* Schröd. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

Micractinium pusillum Fresenius. PIKE: Mississippi River at mile 288.5, August, 1985; Pigeon Creek, May, 1985.

**M. pusillum* var. *elegans* G.M. Smith. PIKE: Mississippi River at mile 297.3, August, 1985.

**Monoraphidium contortum* (Thur.) Kom.-Legn. CASS: Indian Creek, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Beebe Creek, April, 1985; McCraney Creek, April and May, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, 1985.

**M. irregulare* (G.M. Smith) Kom.-Legn. PIKE: Beebe Creek, April, 1985; Hadley Creek, April, 1985; McCraney Creek, May, 1985.

**M. minutum* (Näg.) Kom.-Legn. CASS: New Pankey Pond Ditch, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Blue Creek, April, 1985; McCraney Creek, May, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

M. mirabile (W. & G.S. West) Pank. PIKE: Bay Creek, April, 1985; Pigeon Creek, May, 1985.

**M. tortile* (W. & G.S. West) Kom.-Legn. CASS: India Creek, June, 1982; New Pankey Pond Ditch, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Bay Creek, April, 1985; Pigeon Creek, May, 1985.

**Oocystis lacustris* Chod. CASS: Indian Creek, June, 1982.

**O. pusilla* Hansg. PIKE: Mississippi River at miles 288.5 and 293, August, 1985.

Pediastrum boryanum (Turp.) Menegh. PIKE: Mississippi River at mile 288.5, August, 1985.

P. duplex var. *clathratum* (A. Braun) Lag. CASS: Unnamed ditch near Meredosia Lake, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

P. simplex (Meyen) Lemm. PIKE: Mississippi River at mile 288.5, August, 1985.

P. simplex var. *duodenarium* (Bailey) Rabh. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

P. tetras (Ehrenb.) Ralfs. PIKE: Mississippi River at mile 288.5, August, 1985.

**Polyedriopsis spinulosa* (Schmidle) Schmidle. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

Scenedesmus abundans (Kirch.) Chod. PIKE: McCraney Creek, April and May, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

**S. abundans* var. *brevicauda* G.M. Smith. PIKE: Hadley Creek, April, 1985.

S. acuminatus (Lag.) Chod. PIKE: Hadley Creek, April, 1985; McCraney Creek, May, 1985; Mississippi River at miles 288.5 and 297.3, August, 1985; Pigeon Creek, May, 1985.

**S. acutus* Meyen. PIKE: McCraney Creek, April and May, 1985.

S. bijuga (Turp.) Lag. PIKE: McCraney Creek, April and May, 1985.

S. denticulatus Lag. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

S. dimorphus (Turp.) Kütz. CASS: Unnamed ditch near Meredosia Lake, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

S. opoliensis P. Richter. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985; Pigeon Creek, May, 1985.

S. quadricauda (Turp.) de Bréb. CASS: Indian Creek, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982. PIKE: McCraney Creek, May, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, 1985.

Schroederia seigera (Schröd.) Lemm. CASS: Indian Creek, June, 1982.

**Tetraedron incus* (Teil.) G.M. Smith. PIKE: Mississippi River at mile 288.5, August, 1985.

T. muticum (A. Braun) Hansg. PIKE: McCraney Creek, May, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, 1985.

**T. pentaedricum* W. & G.S. West, PIKE: Mississippi River at miles 293 and 297.3, August, 1985.

**Tetrastrum heteracanthum* (Nordst.) Chod. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

T. staurogeniaeforme (Schröd.) Lemm. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, 1985.

**Treubaria planctonica* (G.M. Smith) Korš. PIKE: Hadley Creek, April, 1985; Kiser Creek, April, 1985.

**T. setigera* (Arch.) G.M. Smith. PIKE: Mississippi River at mile 288.5, August, 1985.

Zygnematales

Closterium acerosum (Schrank) Ehrenb. CASS: Indian Creek, June, 1982.

C. moniliferum (Bory) Ehrenb. MORGAN: Willow Creek, June, 1982.

Staurastrum leptocladum var. *sinuatum* Wolle. CASS: Indian Creek, June, 1982; New Pankey Pond Ditch, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982. MORGAN: Willow Creek, June, 1982

CHRYSOPHYTA

Bacillariophyceae

Centrales

**Coscinodiscus lacustris* Grun. PIKE: Mississippi River at mile 288.5, August, 1985.

Cyclotella atomus Hust. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, September and October, 1985.

C. meneghiniana Kütz. PIKE: Bay Creek, September, 1985; Beebe Creek, April and October, 1985; Blue Creek, October, 1985; Hadley Creek, April and October, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, October, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, September and October, 1985.

C. ocellata Pant. PIKE: Mississippi River at mile 297.3, August, 1985; Pigeon Creek, September, 1985.

C. pseudostelligera Hust. PIKE: Mississippi River at mile 297.3, August, 1985.

**C. stelligera* Cl. & Grun. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

**Melosira distans* var. *alpigena* Grun. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

M. granulata (Ehrenb.) Ralfs. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

M. granulata var. *angustissima* Müll. PIKE: Bay Creek, September, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, October, 1985.

M. italica (Ehrenb.) Kütz. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985; Pigeon Creek, September, 1985.

M. varians C.A. Ag., PIKE: Hadley Creek, April, 1985; Kiser Creek, October, 1985.

**Stephanodiscus alpinus* Hust. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

S. hantzschii Grun. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985; Pigeon Creek, May, 1985.

**S. hantzschii* f. *tenuis* Håk. & Stoerm. PIKE, Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

**S. invisitatus* Hohn at Hellerman. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

S. minutulus (Kütz.) Cleve & Möll. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, September and October, 1985.

S. niagarae Ehrenb. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

**S. parvus* Stoerm. & Håk. PIKE: Pigeon Creek, October, 1985.

**Thalassiosira fluviatilis* Hust. PIKE: Kiser Creek, September, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, September, 1985.

Pennales

**Achnanthes affinis* Grun. PIKE: Beebe Creek, April, 1985.

A. exigua Grun. PIKE: Bay Creek, April, 1985; Beebe Creek, April and October, 1985; Kiser Creek, September, 1985; McCraney Creek, October, 1985.

A. lanceolata Bréb *ex* Kütz. PIKE: Beebe Creek, April and October, 1985; Blue Creek, April, 1985; Kiser Creek, April and September, 1985; McCraney Creek, April and October, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.

A. lanceolata var. *dubia* Grun. PIKE: Hadley Creek, April and October, 1985; Kiser Creek, April, September and October, 1985; Pigeon Creek, September and October, 1985.

**A. linearis* (W. Sm.) Grun. PIKE: Mississippi River at mile 297.3, August, 1985.

A. microcephala (Kütz.) Grun. PIKE: Kiser Creek, October, 1985; Mississippi River at mile 297.3, August, 1985.

A. minutissima Kütz. PIKE: Beebe Creek, April and September, 1985; Kiser Creek, April and October, 1985; McCraney Creek, September, 1985.

**Amphora ovalis* var. *affinis* (Kütz.) V.H. *ex* DeT. PIKE: McCraney Creek, April, 1985.

**A. perpusilla* (Grun.) Grun. PIKE: Kiser Creek, April, 1985.

**A. veneta* Kütz. PIKE: Blue Creek, October, 1985; Kiser Creek, September, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.

Asterionella formosa Hass. PIKE: Beebe Creek, April and October, 1985; Kiser Creek, September and October, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.

Bacillaria paradoxa Gmel. PIKE: Mississippi River at mile 297.3, August, 1985.
Caloneis amphisbaena (Bory) Cl. PIKE: McCraney Creek, April, 1985.
C. bacillum (Grun.) Cl. PIKE: Kiser Creek, April and September, 1985; Pigeon Creek, September, 1985.
C. ventricosa (Ehrenb.) Meist. PIKE: Hadley Creek, September, 1985.
**C. ventricosa* var. *truncatula* (Grun.) Meist. PIKE: Beebe Creek, April, 1985; Kiser Creek, April, 1985.
**Cocconeis diminuta* Pant. PIKE: Beebe Creek, April, 1985; Hadley Creek, April, 1985.
C. pediculus Ehrenb. PIKE: Beebe Creek, October, 1985; Blue Creek, October, 1985; Hadley Creek, April and October, 1985; Kiser Creek, April and October, 1985.
**C. placentula* var. *euglypta* (Ehrenb.) Cl. PIKE: Kiser Creek, September, 1985; Mississippi River at mile 297.3, August, 1985.
C. placentula var. *lineata* (Ehrenb.) V.H. PIKE: Beebe Creek, October, 1985; Kiser Creek, April, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.
**Cylindrotheca gracilis* (Bréb.) Grun. PIKE: Pigeon Creek, October, 1985.
Cymatopleura librile (Ehrenb.) Pant. PIKE: Beebe Creek, April, 1985; McCraney Creek, April, 1985; Pigeon Creek, May, September and October, 1985.
Cymbella affinis Kütz. PIKE: Beebe Creek, April and September, 1985; Hadley Creek, April, 1985; McCraney Creek, April and May, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, May, 1985.
C. cymbiformis Ag. PIKE: Beebe Creek, September, 1985.
**C. grossestriata* O. Müll. PIKE: Blue Creek, April, 1985.
**C. minuta* var. *pseudogracilis* (Choln.) Reim. PIKE: Beebe Creek, September and October, 1985; Kiser Creek, October, 1985; Pigeon Creek, October, 1985.
**C. minuta* var. *silesiaca* (Bleisch *ex* Rabh.) Reim. PIKE: Bay Creek, September, 1985; Beebe Creek, April, 1985; Blue Creek, April, 1985; Hadley Creek, April, September and October, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, October, 1985; Pigeon Creek, May, September and October, 1985.
**C. muelleri* f. *ventricosa* (Temp. & Perag.) Reim. PIKE: Hadley Creek, September, 1985.
C. naviculiformis Auersw. *ex*. Heib. PIKE: Pigeon Creek, October, 1985.
C. triangulum (Ehrenb.) Cl. PIKE: Kiser Creek, September, 1985.
C. tumida (Bréb. *ex* Kütz.) V.H. PIKE: Hadley Creek, April, September and October, 1985; Kiser Creek, April and September, 1985; McCraney Creek, September, 1985; Pigeon Creek, September, 1985.
Diatoma vulgare Bory. PIKE: McCraney Creek, May, 1985.
**Fragilaria construens* var. *venter* (Ehrenb.) Grun. PIKE: McCraney Creek, September, 1985; Mississippi River at mile 288.5, August, 1985.
F. crotonensis Kitton. PIKE: Beebe Creek, April and October, 1985; Kiser Creek, September and October, 1985; Mississippi River at mile 288.5, August, 1985.
F. pinnata Ehrenb. PIKE: Pigeon Creek, October, 1985.
Gomphonema acuminatum Ehrenb. PIKE: Beebe Creek, April, 1985; Hadley Creek, October, 1985.
**G. acuminatum* var. *pusilla* Grun. PIKE: Beebe Creek, September, 1985.

G. angustatum (Kütz.) Rabh. PIKE: Bay Creek, April, 1985; Beebe Creek, April, 1985; Blue Creek, April, September and October, 1985; Hadley Creek, April, 1985; Kiser Creek, April and October, 1985; McCraney Creek, April, 1985.

**G gracile* Ehrenb. PIKE: Kiser Creek, October, 1985.

G. intricatum var. *vibrio* (Ehrenb.) Cl. PIKE: Beebe Creek, September, 1985.

G. olivaceum (Lyngb.) Kütz. PIKE: Bay Creek, April, 1985; Beebe Creek, April and September, 1985; Blue Creek, April, 1985; Hadley Creek, April, 1985; Kiser Creek, April, 1985; McCraney Creek, April, 1985; Pigeon Creek, May and October, 1985.

G. parvulum Kütz. PIKE: Beebe Creek, April, September and October, 1985; Blue Creek, September and October, 1985; Hadley Creek, April, September and October, 1985; Kiser Creek, April and September, 1985; McCraney Creek, September, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, September and October, 1985.

G. sphaerophorum Ehrenb. PIKE: Hadley Creek, October, 1985.

**G. tenellum* Kütz. PIKE: Bay Creek, September, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.

**G. tergestinum* (Grun.) Fricke. PIKE: Bay Creek, October, 1985; Beebe Creek, April and October, 1985; Blue Creek, October, 1985; Hadley Creek, October, 1985; Kiser Creek, September, 1985; McCraney Creek, October, 1985.

G. truncatum Ehrenb. PIKE: Hadley Creek, April, 1985; McCraney Creek, April, 1985.

G. truncatum var. *capitatum* (Ehrenb.) Patr. PIKE: Beebe Creek, October, 1985; Hadley Creek, April, 1985.

**G. ventricosum* Greg. PIKE: Kiser Creek, September, 1985.

Gyrosigma scalproides (Rabh.) Cl. PIKE: Beebe Creek, September and October, 1985; Hadley Creek, September, 1985; Kiser Creek, September and October, 1985; Pigeon Creek, October, 1985.

G. spencerii (Quek.) Griff. & Henfr. PIKE: Beebe Creek, September and October, 1985; Hadley Creek, October, 1985; McCraney Creek, September, 1985; Mississippi River at mile 288.5, August, 1985; Pigeon Creek, September and October, 1985.

Meridion circulare (Grev.) Ag. PIKE: Bay Creek, April, 1985.

Navicula capitata Ehrenb. PIKE: Bay Creek, September, 1985; Blue Creek, September and October, 1985; Hadley Creek, October, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, May, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.

**N. cincta* (Ehrenb.) Ralfs. PIKE: Bay Creek, September, 1985; Beebe Creek, April and September, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, September, 1985; Pigeon Creek, September, 1985.

**N. circumtexta* Meist. *ex* Hust. PIKE: Mississippi River at mile 297.3, August, 1985.

N. cryptocephala Kütz. PIKE: Beebe Creek, April, 1985; Hadley Creek, April and October, 1985; Kiser Creek, April, September and October, 1985; Pigeon Creek, October, 1985.

N. cryptocephala var. *veneta* (Kütz.) Rabh. PIKE: Beebe Creek, April and October, 1985.

N. cuspidata (Kütz.) Kütz. PIKE: Bay Creek, September, 1985; Hadley Creek, October, 1985; Kiser Creek, April and September, 1985; Pigeon Creek, May, 1985.

N. decussis ostr. PIKE: Bay Creek, April, September and October, 1985; Beebe Creek, April, September and October, 1985; Blue Creek, September, 1985; Hadley Creek, April, September and October, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, April, September and October, 1985; Mississippi River at miles 288.5 and 297.3, August, 1985; Pigeon Creek, May, September and October, 1985.

**N. heufleri* Grun. PIKE: Bay Creek, April, 1985.

N. graciloides A. Mayer, PIKE: Beebe Creek, October, 1985; Hadley Creek, September, 1985.

**N. gregaria* Donkin. PIKE: Bay Creek, October, 1985; Beebe Creek, October, 1985; Hadley Creek, October, 1985; Kiser Creek, September and October, 1985; McCraney Creek, October, 1985; Pigeon Creek, October, 1985.

**N. integra* (W. Sm.) Ralfs. PIKE: Hadley Creek, April, 1985; Kiser Creek, April, 1985.

**N. lanceolata* (Ag.) Ehrenb. PIKE: Kiser Creek, October, 1985.

**N. menisculus* var. *upsaliensis* (Grun.). PIKE: Bay Creek, October, 1985; Beebe Creek, October, 1985; Hadley Creek, April and October, 1985; Kiser Creek, April and October, 1985; McCraney Creek, September and October, 1985; Pigeon Creek, October, 1985.

**N. minuscula* Grun. PIKE: Bay Creek, April, 1985; Beebe Creek, April, 1985; Hadley Creek, April, 1985; Kiser Creek, April, 1985; McCraney Creek, April, 1985.

**N. minuscula* var. *muralis* (Grun.) Lange-Bert. PIKE: Blue Creek, September, 1985; Kiser Creek, October, 1985; Pigeon Creek, October, 1985.

N. mutica Kütz. PIKE: Beebe Creek, September, 1985; Pigeon Creek, October, 1985.

**N. mutica* var. *cohnii* (Hilse) Grun. PIKE: Beebe Creek, September, 1985.

**N. phyllepta* Kütz. PIKE: Bay Creek, April and September, 1985; Beebe Creek, April and September, 1985; Hadley Creek, April, 1985; Kiser Creek, April, 1985; McCraney Creek, May, 1985; Mississippi River at mile 288.5, August, 1985; Pigeon Creek, May, 1985.

**N. placentula* (Ehrenb.) Kütz. PIKE: Mississippi River at mile 297.3, August, 1985.

N. protracta Grun. PIKE: Beebe Creek, April, 1985; Kiser Creek, April, 1985.

N. pupula Kütz. PIKE: Bay Creek, September, 1985; Beebe Creek, April, 1985; Blue Creek, September and October, 1985; Kiser Creek, September, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, May, September and October, 1985.

**N. pygmaea* Kütz. PIKE: Bay Creek, September, 1985; Blue Creek, September, 1985; Kiser Creek, September and October, 1985; Pigeon Creek, October, 1985.

N. radiosa Kütz. PIKE: Hadley Creek, April, 1985.

N. rhyncocephala Kütz. PIKE: Beebe Creek, April, 1985.

N. salinarum var. *intermedia* (Grun.) Cl. PIKE: Bay Creek, April, 1985; Beebe Creek, April and October, 1985; Hadley Creek, April and October, 1985; Kiser Creek, October, 1985; McCraney Creek, April, 1985; Pigeon Creek, May and October, 1985.

**N. secreta* var. *apiculata* Patr. PIKE: Mississippi River at mile 297.3, August, 1985.

**N. symmetrica* Patr. PIKE: Beebe Creek, September, 1985.

N. tripunctata (O.F. Müll.) Bory. PIKE: Beebe Creek, April, 1985; Hadley Creek, April, 1985; Kiser Creek, October, 1985; Pigeon Creek, October, 1985.

**N. trivialis* Lange-Bert. PIKE: Bay Creek, April, 1985; Beebe Creek, April, 1985; Blue Creek, April, September and October, 1985; Hadley Creek, April, 1985; Kiser Creek, April, 1985; McCraney Creek, April and May, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, May, September and October, 1985.

N. viridula (Kütz) Kütz. *emend.* V.H. PIKE: Bay Creek, September, 1985; Beebe Creek, September, 1985; Hadley Creek, October, 1985; Kiser Creek, October, 1985; McCraney Creek, September and October, 1985; Pigeon Creek, September and October, 1985.

**N viridula* var. *linearis* Hust. PIKE: Bay Creek, April and September, 1985; Beebe Creek, April, September and October, 1985; Hadley Creek, April, 1985; Kiser Creek, April and September, 1985; McCraney Creek, September and October, 1985; Pigeon Creek, May, September and October, 1985.

**N. viridula* var. *rostellata* (Kütz.) Cl. PIKE: Bay Creek, October, 1985; Hadley Creek, September and October, 1985; Kiser Creek, October, 1985; McCraney Creek, October, 1985; Pigeon Creek, September and October, 1985.

**N. zanoni* Hust. PIKE: Beebe Creek, September, 1985.

**Neidium affine* var. *amphirhynchus* (Ehrenb.) Cl. PIKE: Mississippi River at mile 297.3, August, 1985.

**N. affine* var. *humerus* Reim. PIKE: Hadley Creek, September, 1985.

N. dubium (Ehrenb.) Cl. PIKE: Hadley Creek, April, 1985; Kiser Creek, April, 1985.

Nitzschia acicularis W. Sm. PIKE: Bay Creek, April, 1985; Beebe Creek, April, September and October, 1985; Blue Creek, April, 1985; Hadley Creek, April, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, May and October, 1985; Mississippi River at mile 288.5, August, 1985; Pigeon Creek, May, September and October, 1985.

N. amphibia Grun. PIKE: Beebe Creek, September and October, 1985; Hadley Creek, October, 1985; Kiser Creek, October, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, September, 1985.

N. angustata (W. Sm.) Grun. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

**N. angustata* var. *acuta* Grun. PIKE: Hadley Creek, October, 1985.

N. apiculata (Greg.) Grun. PIKE: Bay Creek, September, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.

**N. brevissima* Grun. *in* V.H. PIKE: Pigeon Creek, May, 1985.

**N. communis* Rabh. PIKE: Pigeon Creek, October, 1985.

N. commutata Grun. PIKE: Pigeon Creek, October, 1985.

N. dissipata (Kütz.) Grun. PIKE: Bay Creek, April, 1985; Beebe Creek, April and October, 1985; Blue Creek, April, 1985; Hadley Creek, April and October, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, May and October, 1985; Pigeon Creek, May and October, 1985.

**N. epiphytica* Hust. PIKE: Pigeon Creek, October, 1985.

**N. fonticola* Grun. PIKE: Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.

**N. frustulum* (Kütz.) Grun. PIKE: Bay Creek, April and September, 1985; Beebe Creek, September and October, 1985; Blue Creek, September and October, 1985; Hadley Creek, April, 1985; Kiser Creek, April, September and October,

1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, October, 1985.

**N. gandersheimiensis* Krasske. PIKE: Bay Creek, April and October, 1985; Beebe Creek, April and October, 1985; Blue Creek, April and October, 1985; Hadley Creek, April, 1985; Kiser Creek, April, September and October, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, May and October, 1985.

**N. gracilis* Hantz. PIKE: Bay Creek, April, 1985; Beebe Creek, April, 1985.

**N. hantzschiana* Rabh. PIKE: Mississippi River at mile 288.5, August, 1985.

N. hungarica Grun. PIKE: Bay Creek, April, 1985; Blue Creek, October, 1985; Hadley Creek, October, 1985; Mississippi River at mile 297.3, August, 1985.

N. linearis W. Sm. PIKE: Bay Creek, April, 1985; Beebe Creek, April and October, 1985; Blue Creek, April, 1985; Hadley Creek, April and October, 1985; Kiser Creek, April and October, 1985; McCraney Creek, May and October, 1985; Pigeon Creek, May and October, 1985.

**N. microcephala* Grun. PIKE: Mississippi River at mile 297.3, August, 1985.

**N. minutula* Grun. PIKE: Mississippi River at mile 297.3, August, 1985.

N. palea (Kütz.) W. Sm. PIKE: Bay Creek, April, September and October, 1985; Beebe Creek, April, September and October, 1985; Blue Creek, April, September and October, 1985; Hadley Creek, April, September and October, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, May and October, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, September and October, 1985.

**N. paleacea* Grun. PIKE: Bay Creek, April, 1985.

**N. parvula* Lewis. PIKE: Beebe Creek, September, 1985; Hadley Creek, October, 1985; Kiser Creek, September and October, 1985.

**N. recta* Hantz. PIKE: Hadley Creek, October, 1985; Mississippi River at mile 297.3, August, 1985.

**N. romana* Grun. PIKE: Hadley Creek, October, 1985; Mississippi River at mile 288.5, August, 1985.

**N. rostellata* Hust. PIKE: Mississippi River at mile 288.5, August, 1985.

N. sinuata var. *tabellaria* Grun. PIKE: Pigeon Creek, October, 1985.

**N. tryblionella* Hantz. PIKE: Bay Creek, September, 1985.

**N. tryblionella* var. *debilis* (Arn.) A. Mayer. PIKE: Beebe Creek, October, 1985; Kiser Creek, October, 1985.

**N. tryblionella* var. *victoriae* Grun. PIKE: Bay Creek, April, 1985; Kiser Creek, September, 1985; Mississippi River at mile 297.3, August, 1985.

**Pinnularia mesogongyla* Ehrenb. PIKE: Hadley Creek, September, 1985.

Rhoicosphenia curvata (Kütz.) Grun. *ex* Rabh. PIKE: Mississippi River at mile 297.3, August, 1985.

Surirella angustata Kütz. PIKE: Bay Creek, April, 1985; Beebe Creek, October, 1985; Hadley Creek, April, 1985; Kiser Creek, April and September, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, October, 1985.

S. *ovata* Kütz. PIKE: Bay Creek, April and September, 1985; Beebe Creek, April and October, 1985; Blue Creek, April, September and October, 1985; Hadley Creek, April and October, 1985; Kiser Creek, April, September and October, 1985; McCraney Creek, April, May and October, 1985; Pigeon Creek, May and October, 1985.

S. *ovata* var. *pinnata* (W. Sm.) Rabh. PIKE: Kiser Creek, October, 1985.

*S. *ovata* var. *pinnata* f. *gibbosa* Tynni. PIKE: Pigeon Creek, October, 1985.
S. *spiralis* Kütz. PIKE: Hadley Creek, October, 1985.
S. *tenera* Greg. PIKE: Pigeon Creek, October, 1985.
Synedra acus Kütz. PIKE: Hadley Creek, April and October, 1985; Kiser Creek, April, 1985; McCraney Creek, May, 1985; Pigeon Creek, May, 1985.
S. *delicatissima* var. *angustissima* Grun. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.
S. *rumpens* Kütz. PIKE: Beebe Creek, September, 1985.
*S. *rumpens* var. *familiaris* (Kütz.) Hust. PIKE: Bay Creek, April, 1985; Hadley Creek, April, 1985; Kiser Creek, April and October, 1985; Pigeon Creek, May, 1985.
S. *ulna* (Nitz.) Ehrenb. PIKE: Blue Creek, April, 1985; Hadley Creek, April, 1985.
Tabellaria fenestrata (Lyngb.) Kütz. PIKE: Beebe Creek, April, 1985; Hadley Creek, April, 1985; Kiser Creek, October, 1985; McCraney Creek, October, 1985.

Chrysophyceae

Chrysomonadales

Dinobryon divergens Imhof. CASS: Indian Creek, June, 1982; New Pankey Pond Ditch, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982. MORGAN: Willow Creek, June, 1982.

Xanthophyceae

Heterococcales

**Ophiocytium capitatum* var. *longispinum* (Moebius) Lemm. PIKE: Mississippi River at mile 288.5, August, 1985.
Peroniella planctonica G.M. Smith. PIKE: Kiser Creek, April, 1985.

Heterotrichales

Tribonema minus (Wille) Hazen. MORGAN: Willow Creek, June, 1982.

CRYPTOPHYTA

Cryptophyceae

Cryptomonadales

**Chilomonas paramaecium* Ehrenb. CASS: Unnamed ditch near Meredosia Lake, June, 1982.
**Chroomonas coerulea* (Geitl.) Skuja. PIKE: Kiser Creek, April, 1985.
**Cryptomonas erosa* Ehrenb. CASS: Indian Creek, June, 1982; New Pankey Pond Ditch, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Pigeon Creek, May, 1985.
**C. marssonii* Skuja. MORGAN: Willow Creek, June, 1982.
**C. ovata* Ehrenb. CASS: Unnamed ditch near Meredosia Lake, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Hadley Creek, April, 1985; Kiser Creek, April, 1985; Pigeon Creek, May, 1985.
**C. pyrenoidifera* Geitl. MORGAN: Willow Creek, June, 1982. PIKE: Mississippi River at mile 288.5, August, 1985.

*C. *rostratiformis* Skuja. CASS: New Pankey Pond Ditch, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982.

**Rhodomonas minuta* var. *nannoplanctica* Skuja. CASS: Indian Creek, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Mississippi River at mile 288.5, August, 1985.

CYANOPHYTA

Myxophyceae

Chroococcales

**Chroococcus disperus* (Keissl.) Lemm. PIKE: Bay Creek, April, 1985.

**C. disperus* var. *minor* G.M. Smith. CASS: Unnamed ditch near Meredosia Lake, June, 1982.

C. minutus (Kütz.) Näg. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

**Marssoniella elegans* Lemm. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

Merismopedia glauca (Ehrenb.) Näg. CASS: New Pankey Pond Ditch, June, 1982. PIKE: Mississippi River at mile 297.3, August, 1985.

**M. punctata* Meyen. PIKE: Mississippi River at mile 297.3, August, 1985.

M. tenuissima Lemm. PIKE: Mississippi River at miles 288.5, 293 and 297.3, August, 1985.

Microcystis aeruginosa Kütz. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

Hormogonales

Anabaena circinalis (Kütz.) Rabh. MORGAN: Willow Creek, June, 1982. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985.

Aphanizomenon flos-aquae (L.) Ralfs. MORGAN: Willow Creek, June, 1982. PIKE: Mississippi River at miles 288.5 and 293, August, 1985.

**Oscillatoria limnetica* Lemm. CASS: New Pankey Pond Ditch, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982. PIKE: Bay Creek, April, 1985; Blue Creek, April, 1985; Hadley Creek, April, 1985; McCraney Creek, April and May, 1985; Mississippi River at miles 288.5, 293 and 297.3, August, 1985; Pigeon Creek, May, 1985.

O. subbrevis Schmidle. CASS: Indian Creek, June, 1982; New Pankey Pond Ditch, June, 1982. PIKE: Bay Creek, April, 1985; Hadley Creek, April, 1985; Kiser Creek, April, 1985; Pigeon Creek, May, 1985.

O. tenuis C.A. Ag. CASS: Unnamed ditch near Meredosia Lake, June, 1982. PIKE: Beebe Creek, April, 1985; Blue Creek, April, 1985; Hadley Creek, April, 1985; Kiser Creek, April, 1985; Mississippi River at mile 297.3, August, 1985; Pigeon Creek, May, 1985.

**Pseudoanabaena galeata* Bocher. CASS: Indian Creek, June, 1982; Unnamed ditch near Meredosia Lake, June, 1982. PIKE: Bay Creek, April, 1985; Kiser Creek, April, 1985; McCraney Creek, May, 1985; Mississippi River at mile 297.3, August, 1985.

Spirulina major Kütz. CASS: New Pankey Pond Ditch, June, 1982.

**S. meneghiniana* Zanard *ex* Gomont. PIKE: Mississippi River at mile 288.5, August, 1985.

EUGLENOPHYTA

Euglenophyceae

Euglenales

Euglena acus Ehrenb. CASS: Indian Creek, June, 1982. PIKE: Pigeon Creek, May, 1982.

E. acutissima Lemm. CASS: Unnamed ditch near Meredosia Lake, June, 1982.

E. gracilis Klebs. PIKE: Bay Creek, April, 1985; Beebe Creek, April, 1985; McCraney Creek, April and May, 1985; Pigeon Creek, May, 1985.

E. proxima Dang. CASS: Unnamed ditch near Meredosia Lake, June, 1982.

E. spirogyra Ehrenb. CASS: Indian Creek, June, 1982; New Pankey Pond Ditch, June, 1982.

E. viridis Ehrenb. PIKE: Blue Creek, April, 1985; Hadley Creek, April, 1985; Pigeon Creek, May, 1985.

Phacus acuminata Stokes. CASS: Indian Creek, June, 1982.

**Phacus anacoelus* Stokes. PIKE: Pigeon Creek, May, 1985.

P. longicauda (Ehrenb.) Duj. CASS: New Pankey Pond Ditch, June, 1982. MORGAN: Willow Creek, June, 1982. PIKE: Mississippi River at mile 297.3, August, 1985.

P. pleuronectes (Müll.) Duj. CASS: Indian Creek, June, 1982; New Pankey Pond Ditch, June, 1982. PIKE: Mississippi River at miles 288.5 and 297.3, August, 1985; Pigeon Creek, May, 1985.

P. pyrum (Ehrenb.) Stein. PIKE: Pigeon Creek, May, 1985.

Trachelomonas acanthostoma (Stokes) Defl. PIKE: Pigeon Creek, May, 1985.

T. crebea (Kell.) Defl. PIKE: Bay Creek, April, 1985; Pigeon Creek, May, 1985.

T. globularis (Awer.) Lemm. PIKE: Pigeon Creek, May, 1985.

T. intermedia Dang. PIKE: Blue Creek, April, 1985; Kiser Creek, April, 1985; Mississippi River at mile 288.5, August, 1985.

T. tambowika Swirenko. PIKE: Pigeon Creek, May, 1985.

T. volvocina Ehrenb. PIKE: Pigeon Creek, May, 1985.

PYRROPHYTA

Dinophyceae

Peridiniales

**Peridinium limbatum* (Stokes) Lemm. MORGAN: Willow Creek, June, 1982.

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SUCCESSIONAL CHANGES IN A SALIX NIGRA (SALICACEAE) FOREST IN SOUTH-CENTRAL OKLAHOMA

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ABSTRACT

Periodic samplings of the vegetation of a 30-year-old, 2.02 ha, black willow (*Salix nigra*) forest on the north shore of Lake Texoma in south-central Oklahoma revealed the gradual replacement of S. *nigra* by a mixture of shade-tolerant bottomland hardwoods. Between 1960 and 1976, total tree density (trees/ha) decreased from 882 to 840, and S. *nigra* density decreased from 882 to 544. Mixed bottomland hardwood tree density increased from 0 to 296. Concomitantly, total basal area (m^2/ha) increased from 25.8 to 53.2, with black willow being the sole contributor to basal area in 1960 and the primary contributor in 1976. The decreased density of S. *nigra* was due to its inability to reproduce in the willow forest. Little change was observed in the species composition of the vine, shrub, and herbaceous stratum, but marked changes were noted for various species.

INTRODUCTION

Willow Flats is a 30-year-old, 2.02 ha, black willow (*Salix nigra* Marsh.) forest located on the north shore of Lake Texoma approximately 1.7 km west of the University of Oklahoma Biological Station; Marshall County, Oklahoma (R5E, T8S, Sec.7). The forest occurs on Quaternary river-terrace sands at an elevation of 189 m, and, because it lies between the minimum pool elevation (188 m) and flood control levels of the reservoir, periodically floods. Stands of S. *nigra* or *Populus deltoides* are locally common along waterways and around impoundments. Both species are recognized as representative of the pioneer stage of succession in newly exposed areas with fluctuating water levels; the successional changes that occur after their establishment have been described (Shull 1922 and 1944, Barclay 1924, Shelford 1954, Hosner and Minckler 1963, Wilson 1970).

According to local residents, the land on which the forest exists was cultivated, and few willows were present prior to impoundment of the Red River by the U.S. Army Corps of Engineers to form Lake Texoma in 1944-45. The first ecological studies of Willow Flats were conducted in 1960 (Prophet 1960, Penfound 1961). The forest consisted of a pure stand of *Salix nigra*. Subsequent sampling was conducted in 1964 and 1965 (Penfound 1965, Dent 1965, Parks and Barclay 1966), and revealed that S. *nigra* still dominated the canopy, although several other trees were also present. Impenetrable vine growth prevented sampling some areas in the forest.

In the summer of 1976 additional sampling of Willow Flats was conducted. The objective of our study was to describe the vegetation, compare results with previous studies, and document successional changes that had occurred in the intervening years. Johnson (1984) investigated a nearby area and reported that a black willow forest was being replaced primarily by *Celtis laevigata* and *Diospyros virginiana*.

METHODS

In order to obtain data comparable to that of previous studies, the same sampling methods were employed with minor modifications. The boundaries of the original 0.75 ha rectangular sampling area were established by marking each corner tree with a broad red-painted band (Dent 1965). Three of the four corner trees were relocated, and the position of the fourth was deduced. The sampling area was divided into 186 quadrats (2.0 × 20.24 m each), from which 30 quadrats were randomly selected for sampling.

Trees (≥7.62 cm DBH) and tree saplings (<7.62 cm DBH) were sampled in each quadrat by the arms-length rectangle method of Penfound and Rice (1957). Their method was modified slightly due to the almost impenetrable growth of shrubs and vines in the study area. A 20.24 m cord was used to establish quadrat length and a meter stick to establish width. Species, number of individuals, and diameter-at-breast-height (DBH) were determined for each quadrat. Shrub, vine, and herbaceous species were sampled in a 2.0 × 2.0 m nested quadrat located at the west end of each of the 30 larger quadrats. Species, number of individuals, and percent aerial cover were determined. Aerial cover was estimated using the Braun-Blanquet system, with each cover class being assigned a numerical value (Oosting 1956). The five cover classes and their assigned values were: 0-5% = 1; 5-25% = 3; 25-50% = 5; 50-75% = 7; and 75-100% = 9. Where aerial cover is listed in the tabular

material, the numbers represent the additive values of the cover classes. From these data, density, basal area, and relative importance for trees, and density, aerial cover, frequency, and relative importance for shrubs, vines, and herbs were calculated for each species. Voucher specimens were deposited in the University of Oklahoma Biological Station herbarium. Nomenclature follows Kartesz and Kartesz (1980).

RESULTS

In 1960 Willow Flats was a forest composed entirely of black willow trees of approximately 15 years of age and averaged 16.5 m (12.5-21.0 m) in height (Prophet 1960, Penfound 1961). Seedlings were absent, and saplings were rare. Seedlings of *Diospyros virginiana* and *Morus rubra* were present. In addition, two other unspecified tree species were observed in the area. In 1965 the canopy still consisted entirely of *S. nigra* (Dent 1965). However, five additional tree-stature species were observed in 1965 (*Morus rubra, Zanthoxylum clava-herculis, Melia azedarach, Celtis laevigata,* and *Ulmus americana*). Saplings of these species, with the exception of *M. azedarach,* plus those of *Maclura pomifera, Gleditsia triacanthos, Rhamnus caroliniana,* and *Juniperus virginiana* were also found in the quadrats with saplings of *S. nigra.* The black willow saplings were primarily stump sprouts.

In the present study thirteen tree species were found (Tables 1 and 2), and, of these, three occurred only as saplings (*Carya illinoensis, G. triacanthos,* and *Z. clava-herculis*). *Salix nigra,* the sole constituent of the canopy for the previous studies, was joined by eight additional tree species as well as several large *Cephalanthus occidentalis* shrubs (Table 1). In general, these additional species coincided with those reported as saplings or seedlings when the forest was in an earlier successional stage (Prophet 1960, Penfound 1961, Dent 1965, Parks and Barclay 1966).

Between 1960 (Prophet 1960) and 1976 total tree density (trees/ha) decreased from 882 to 840 and total basal area (m^2/ha) increased from 26 to 53. The density of black willow decreased from 882 to 544 trees/ha, while that of mixed hardwoods increased from 0 to 296 trees/ha. Large dead willows were found in 23.3% (7 out of 30) of the quadrats, explaining, in part, the decrease in willow density. The black willow basal area increased from 26 to 50 m^2/ha during the same time period.

Observed changes in the tree component of Willow Flats are expected if the ecological requirements of resident species are considered. Differences in germination requirements, shade tolerance, and competitive ability have resulted in the succession to a more rich forest than existed in 1960. Species of willow are considered to be very intolerant of shade, while the species that increased in density and/or basal area, *i.e., Diospyros virginiana, Celtis laevigata,* and *Ulmus americana* are tolerant to intermediate in their ability to compete in light-limited forests (Baker 1949). In addition, *Salix* species have long been recognized as floodplain pioneers (Shull 1922 and 1944, Barclay 1924, Shelford 1954, Weaver 1960, Lindsay *et al.* 1961, Hosner and Minckler 1963, Wilson 1970.). Germination and seedling establishment of *S. nigra* are dependent upon the availability of open, wet, porous soils directly exposed to the sun (McLeod and McPherson 1973). Germination and establishment involve a release of seeds in the late spring or early summer, dispersal onto muddy shores or into water, a slow retreat of the water after spring rains, and the persis-

tence of a band of very wet, open soil (McLeod and McPherson 1973). Conditions of exposed sites, open soils, and fluctuating water levels existed immediately after the creation of Lake Texoma, according to local residents, and persisted on a smaller scale during the present survey. The uniform size of the black willow trees and the lack of seedlings suggest that *Salix nigra* became quickly established in the Willow Flats area over a period of a few years. Shading by the canopy and subsequent establishment of ground-covering shrub, vine, and herbaceous species prevented the establishment of younger willows.

Detailed comparisons of the shrub and vine communities with previous studies are difficult due to lack of comparable data. In 1960 the shrub stratum was sparse (Prophet 1960, Penfound 1961), consisting primarily of *Cephalanthus occidentalis*. By 1965, *C. occidentalis* was reported (Dent 1965) to be "unusually dense", although its relative frequency (10.4) had decreased considerably from Prophet's (1960) value of 30.2. By 1976, the shrub's relative aerial cover and frequency were low especially when compared to those of various vine species. Oosting (1942) noted a similar decline in *C. occidentalis* concomitant with canopy closure.

In 1960, three vine species (*Rubus trivialis, Ampelopsis arborea,* and *Parthenocissus quinquefolia*) were found in the understory of Willow Flats with a total relative frequency of 51.1 (Prophet 1960). By 1965 vines composed 80.9% of the relative aerial cover (Penfound 1965; Table 3). Dense vine growth was also noted in 1965 (Dent 1965, Parks and Barclay 1966). Willow trees were "draped" with *Ampelopsis arborea, Smilax bona-nox,* and *Vitis cinerea,* and the understory consisted of a dense cover of *Rubus* spp. and *Toxicodendron radicans* (Parks and Barclay 1966). In 1976 this same phenomenon was observed; thickets and tangles of those species still provided 77.7% of the relative cover for vine and shrub species (Table 4) and were oftentimes impenetrable. Although species composition apparently did not change between 1960 and 1976, vine cover increased dramatically. Illustrative of this change was the growth of *T. radicans* (Table 3). Prophet (1960) and Penfound (1961) made no mention of this species; however, four years later Penfound (1965) reported a relative aerial cover of 9.5%. Dent (1965) noted that dense growth of this species precluded sampling. Its relative aerial cover in 1976 was 21.9%. *Ampelopsis arborea* and *Parthenocissus quinquefolia* also increased in aerial cover and frequency. All of the vine and shrub species encountered are common in bottomland forests of Oklahoma (Rice 1965).

Abundance of vine growth in black willow communities is well documented (Shull 1922, Oosting 1942, Weaver 1960, Wilson 1970), and the vigorous growth of vines in the vicinity of Willow Flats was previously described (Penfound *et al.* 1965a, Penfound *et al.* 1965b, Parks and Barclay 1966). The last study addressed the ecological role that vines play on the north shore of Lake Texoma and suggested that heavy vine growth with concomitant light reduction limits the next successional stage to shade tolerant species. The presence of *Diospyros virginiana, Maclura pomifera,* and *Celtis laevigata* in the seedling component of Willow Flats supports their interpretation. During the present study we observed vines bending over and breaking tree seedlings, stems, and branches. Similar observations have been reported from northern (Weaver 1960, Wilson 1970) and southeastern (Oosting 1942) bottomlands. This phenomenon may be important in delaying successional changes.

Twenty-five herbaceous species were sampled in 1976 (Table 5), indicating a

decrease in species richness from 1960, when thirty-six herbs were sampled (Prophet 1960, Penfound 1961). As noted with shrubs and vines, lack of historical data precludes detailed comparisons. Only five taxa were identified in 1960; the remaining 31 species were grouped as "other species". In subsequent studies little or no herbaceous data were collected.

When all species except the five identified in the 1960 study are grouped as "other species", it is clear that herbs had increased in both relative cover and frequency (Table 3). *Hydrocotyle verticillata* and *Polygonum hydropiperoides*, both present in 1960, were still dominant herbs in 1976, along with *Boehmeria cylindrica* and *Leersia oryzoides* (Table 5). These species are characteristic of wetlands and moist bottomland forest habitats.

The relative cover and frequency values of *Diodia virginiana* decreased over the years (Table 3). Two other species, *Panicum hians* and *Eupatorium serotinum*, were not found in samples from the herbaceous stratum in 1976. These three species are typical of more open sites than were present in Willow Flats in 1976; their decrease or disappearance was expected, given the increasingly shady conditions of the forest floor.

A pronounced zonation of *Hydrocotyle verticillata*, *Diodia virginiana*, and *Eupatorium serotinum* along a moisture gradient from wet to dry was noted by Prophet (1960) and Penfound (1961). Distinct zonation was not apparent in 1976, although a distribution of plants along a weak moisture gradient was noted. *Hydrocotyle verticillata*, *Leersia oryzoides*, *Polygonum hydropiperoides*, and *Ptilimnium capillaceum* were most abundant in the lower, wetter areas. Species such as *Teucrium canadense*, *Boehmeria cylindrica*, *Solanum* sp., and *Ipomoea* sp. occurred in higher, drier areas.

DISCUSSION

Successional changes and the temporal pattern observed in Willow Flats are similar to those described for other floodplain forests (Shelford 1954, Hosner and Minckler 1963, Crites and Ebinger 1969, Wilson 1970, Johnson 1984). Furthermore, the tree and tree-sapling communities include species found in other bottomland forests in south-central Oklahoma (Bruner 1931, Penfound 1948, Rice and Penfound 1956, Rice 1965). As Shelford (1954), Hosner and Minckler (1963), Wilson (1970), and Robertson *et al.* (1978) noted, the pioneer willow community begins to be replaced by other bottomland hardwood species some 30 to 50 years after establishment. Willow Flats was approximately 30 years old at the time of this study.

The changes observed in the vegetation of Willow Flats between 1960 and 1976 suggest the demise of the black willow forest and the development of a bottomland forest similar to others in the vicinity. The inevitable and increasingly rapid disappearance of *Salix nigra* is indicated by the gradual decline in the density of mature trees; the absence of *S. nigra* seedlings or saplings; the lack of open habitats required for seedling establishment; and the appearance and increasing importance of other tree species in the forest canopy. As bottomland forest succession proceeds, species capable of growth in extremely wet soils will eventually dominate. A gradual change in the shrub, vine, and herbaceous components of Willow Flats is also expected as the canopy cover increases and light becomes increasingly limiting.

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Table 1. Tree species (≥7.62 cm DBH) encountered in 1976 ranked according to decreasing relative importance.

Species	Density (stems/ha)	Basal area (m^2/ha)	Relative Importance
Salix nigra Marsh.	543.6	49.97	79.36
Diospyros virginiana L.	164.8	0.95	10.70
Morus rubra L.	24.7	1.14	2.54
Cephalanthus occidentalis L.[a]	32.9	0.14	2.09
Maclura pomifera (Raf.) Schneid.	24.7	0.30	1.75
Celtis laevigata Willd.	16.6	0.24	1.21
Melia azedarach L.	8.2	0.15	0.63
Ulmus americana L.	8.2	0.12	0.60
Juglans nigra L.	8.2	0.07	0.55
Populus deltoides Bartr. ex Marsh.	8.2	0.07	0.55
Totals	840.1	53.15	99.98

[a]Taxon represented by four small trees; other individuals were typical shrubs (see Table 4).

Table 2. Tree seedlings (<7.62 cm DBH) encountered in 1976 ranked according to decreasing relative importance.

Species	Density (stems/ha)	Basal area (m^2/ha)	Relative Importance
Diospyros virginiana L.	255.3	81.92	56.03
Celtis laevigata Willd.	57.6	17.04	12.13
Maclura pomifera (Raf.) Schneid.	49.4	19.21	12.05
Carya illinoensis (Wang.) K. Koch	49.4	6.42	7.47
Ulmus americana L.	16.6	3.89	3.13
Melia azedarach L.	16.6	2.69	2.70
Morus rubra L.	16.6	2.39	2.59
Gleditsia triacanthos L.	8.2	3.74	2.20
Zanthoxylum clava-herculis L.	8.2	2.39	1.72
Totals	477.9	139.69	100.02

Table 3. Comparison of relative aerial cover and relative frequency values for vine, shrub, and herbaceous species in 1960 (Prophet), 1965 (Penfound), and 1976 (Phillippi *et al.*), ranked according to decreasing values from 1976.

	Relative Aerial Cover			Relative Frequency	
Species	1960	1965	1976	1960	1976
Vine species:					
Rubus spp.	[a]	62.9	31.4	27.9[b]	23.3
Toxicodendron radicans (L.) Kuntz	[a]	9.5	21.9	[a]	16.6
Ampelopsis arborea (L.) Koehne	[a]	8.5	14.2	13.9	19.9
Parthenocissus quinquefolia (L.) Planch.	[a]	[a]	8.8	9.3	13.3
Shrub species:					
Cephalanthus occidentalis L.	[a]	8.3	6.2	30.2	9.0
Herbaceous species:					
"Other species"	20.0	[a]	68.4	42.8	75.8
Hydrocotyle verticillata Thunb.	29.4	0.0	22.6	16.0	11.1
Polygonum hydropiperoides Michx.	6.1	[a]	7.9	5.3	10.3
Diodia virginiana L.	25.3	1.0	1.1	13.3	2.8
Eupatorium serotinum Michaux	10.4	1.0	0.0	9.3	0.0
Panicum hians Ell.	8.8	[a]	0.0	13.3	0.0

[a] Data not available

[b] *Rubus trivialis* according to Prophet (1960).

Table 4. Vine and shrub species encountered in 1976 arranged according to decreasing relative importance.

Species	Density (stems/m^2)	Aerial Cover	Frequency	Relative Importance
Vine species				
Rubus spp.	3.46	86	0.70	29.53
Toxicodendron radicans (L.) Kuntze	4.26	60	0.50	26.72
Ampelopsis arborea (L.) Koehne	0.43	39	0.60	12.79
Parthenocissus quinquefolia (L.) Planch.	1.17	24	0.40	11.16
Vitis spp.	0.06	26	0.20	5.57
Berchemia scandens (Hill) K. Koch	0.48	13	0.17	5.03
Smilax bona-nox L.	0.17	2	0.07	1.57
Shrub species:				
Cephalanthus occidentalis L.	0.11	17	0.27	5.42
Rosa sp.	0.05	4	0.07	1.43
Cornus drummondii C. A. Mey.	0.025	3	0.03	0.78
Totals	10.215	274	3.01	100.00

Table 5. Herbaceous species encountered in 1976 arranged according to decreasing relative importance.

Species	Density (stems/m^2)	Aerial Cover	Frequency	Relative Importance
Hydrocotyle verticillata Thunb.	17.62	60	0.40	28.97
Boehmeria cylindrica (L.) Sw.	3.83	61	0.63	17.35
Leersia oryzoides (L.) Sw.	3.93	35	0.23	10.48
Polygonum hydropiperoides Michx.	2.69	21	0.37	8.76
Ptilimnium capillaceum (Michx.) Raf.	0.76	16	0.20	4.62
Teucrium canadense L.	0.56	10	0.23	3.94
Cynodon dactylon (L.) Pers.	1.51	9	0.10	3.58
Cocculus carolinus (L.) DC.	0.14	9	0.17	2.84
Verbesina sp.	0.33	7	0.17	2.78
[a]	a	a	a	a
Totals	33.13	265	3.61	99.99

[a]Other species found with densities <0.33 stems/m^2, cover <7, frequency <0.17, and relative importances <2.78 were: *Carex* sp., *Solanum* sp., Unidentified umbellifer, *Commelina erecta* L., *Diodia virginiana* L., *Ipomoea* sp., *Conyza canadensis* (L.) Cronq., *Samolus valerandi* L., Unidentified composite, *Panicum* sp., *Lactuca* sp., *Physalis* sp., *Acalypha* sp., Unidentified composite, *Scirpus* sp., *Juncus* sp.

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A STATISTICAL ANALYSIS OF THE ANGIOSPERM VEGETATION IN MILLER-ANDERSON WOODS NATURE PRESERVE IN ILLINOIS

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ABSTRACT

Statistical methods were used to evaluate the relative abundance of 277 angiosperm species growing in 15 sample plots on nine natural habitats of Miller-Anderson Woods Nature Preserve in Illinois. An ordinal log-linear model was selected to explain the data. Habitat affected the number of observed species and their relative abundance. Predictions of the ordinal model in regard to plant taxa relative abundance were the best for the wooded lowlands, northeast facing slopes, and dry old field succession habitats.

INTRODUCTION

Miller-Anderson Woods Nature Preserve contains 320 acres located west of Illinois Route 29 between the junction of Putnam and Bureau Counties (SW 1/4,

Sec. 36, T15N, R9E, 4th P.M. and part of W 1/4, Sec. 6, T14N, R10E, 4th P.M.). The original land parcel was acquired by the Illinois Department of Conservation (IDOC) in 1969 and consisted of 258 acres. Subsequent land purchases by the IDOC have resulted in the current Nature Preserve acreage.

The Nature Preserve was surveyed as part of the Illinois Natural Areas Inventory (unpublished excerpt) by the IDOC in 1977. The survey team identified and described five natural habitats within the Nature Preserve: dry mesic upland forest; mesic upland forest; sedge meadow; successional field; and glacial hill prairie. The survey team described the Nature Preserve as containing old growth uplands, ravines, and valley forests of the Grand Prairie Section of the Grand Prairie Natural Division of Illinois (Schwegman, 1973).

Monoson and Schertz (1985) divided Miller-Anderson Woods into ten natural habitats on the basis of topographic features (Fig. 1). The ten habitats consisted of dry mesic upland forest, south- and southeast facing wooded slopes, wooded lowlands, north-, northeast, and east-facing wooded slopes, dry old field succession, mesic regrowth forest along stream banks, wet old field succession, sedge meadow, regrowth area along new Illinois Route 29, and back water bog area. A hill prairie located in the dry mesic upland forest was given habitat status because of its unique vegetational composition. Fifteen permanent square 100 m^2 plots were placed randomly on the first eight habitat designations and the hill prairie for sampling purposes; the regrowth area along new Illinois Route 29 and the back water bog area were not sampled. The parking lot was included in the 1985 study and represented a recently disturbed area. Several physical factors contributed to the small number of sample plots that were used in the study such as differences in area size of the various habitats, variable flowering times of the taxa, steep topographical features, and other abiotic factors.

Monoson and Schertz (1985) reported that a total of 72 families, 185 genera, and 277 species of angiosperms occurred within the fifteen sample plots. Species of the Compositae, Graminae, and Leguminosae families were the best represented. A possible correlation between the relative abundance of these flowering taxa and certain habitats was suggested by the data.

The objective of the present study was to determine if a relationship existed between the relative abundance of plants found within a sample plot and a specific habitat. This relationship would be ecologically important because plant distribution is regulated by topography, water drainage patterns, light duration and intensity, and nutrient availability within any defined land area.

METHODS AND MATERIALS

The habitats examined in this study were dry mesic upland forest (DMUF), south- and southeast facing slopes (SEFS), wooded lowlands (WL), north-, northeast, and east-facing wooded slopes (NEFS), dry old field succession (DOFS), mesic regrowth along stream banks (MR), wet old field succession (WOFS), sedge meadow (SM), and hill prairie (HP). Sample plots were distributed randomly on a grid of these nine habitats that traversed the Nature Preserve. Numerical distribution was six plots in the DMUF, two in the adjacent SEFS, and one each in the WL, NEFS, DOFS, MR, WOFS, SM, and HP habitats.

For each of the plant taxa found in the initial study (Monoson and Schertz, 1985) the habitat, plot number, relative abundance, and flowering date(s) if observed were recorded. Relative abundance values were determined using a modification of the Hanson (1934) procedure. Relative abundance values were rare = <12, occasional = 12-25, and abundant = >25 plants/plot. The relative abundance data (Table 1) are species numbers found in the sample plots and were not representative of the total abundance for the different habitats.

Initially, the Pearson chi-square test for independence (Bhattacharyya and Johnson, 1977) was used to determine if a relationship between sample plot and plant relative abundance existed. The relationship of habitat to relative abundance was examined by a second application of the chi-square test. The second test used an abbreviated table of data formed by adding abundance numbers for plots within the same habitat, e.g. southeast facing slopes (SEFS) total 12 taxa in rare, 21 taxa in occasional, and 17 taxa in abundant categories. Dry mesic upland forest (DMUF) plots were combined within either the northern or southern plateau areas to allow for possible geographic effects. This separation of DMUF plots resulted in ten habitat designations for the statistical analysis.

Several statistical models were considered in the assessment of the variability of the data. These were the log-linear models of Fienberg (1977) adapted to use habitat as the row variable. This method allowed the logarithm of the expected number in a cell of Table 1 to depend upon (at least) the habitat and the overall frequency in "rare", "occasional" and "abundant" categories. All of the data contained in Table 1 was used because the sample plot was considered to be the basic experimental unit.

The structure of Table 1 included the order of the relative abundance categories — "rare" is less than "occasional" is less than "abundant". Therefore, a log-linear type of model (Agresti, 1984) that had ordinal column categories was considered. This ordinal model was selected for further study.

The ordinal model is described by the equation

$$\log m_{ij} = \mu + \lambda_i + \alpha_j + \tau_i v_j$$

where the variables are defined as follows:

m_{ij} = expected number in a cell in column j with habitat i
μ = overall average of log m_{ij}
λ_i = the direct effect of the i^{th} habitat on the log expected number
α_j = the direct effect of the j^{th} column (abundance category) on the log expected number
τ_i = the interaction effect between habitat i and relative abundance
v_j = relative abundance score (predetermined) reflecting the ordering of the columns: $v_1 = -1$, $v_2 = 0$, $v_3 = 1$

The equation is subject to the conditions $\Sigma\lambda_i = 0$, $\Sigma\alpha_j = 0$, and $\Sigma\tau_i = 0$. The DMUF plots on the northern and southern plateaus were considered to be different habitats for this analysis.

With a minimum number of additional parameters (the τ_i's), the ordinal model allowed a statistical consideration of the concept that the habitat influenced both the number of species per plot and the allocation of these species in each relative abundance category. Habitat would affect only total numbers of species per plot and not relative abundance if the τ_i's were all zero.

Parameter estimation for the model was performed using a FORTRAN program (unpublished) written by the first author. Standard log-linear statistical packages were not appropriate due to both the irregular replication pattern, i.e. variable numbers of plots per habitat, and the ordinal nature of the relative abundance categories. Usually, normal categories are assumed by most log-linear statistical package programs. For each parameter, the partial derivative of the log-likelihood was set to zero, and the resulting system of equations solved numerically using the International Mathematical and Statistical Libraries, Incorporated (IMSL, 1982) subroutine ZSCNT. Subroutine ZSCNT solves a system of nonlinear equations using the secant method. The program was executed on the Bradley University Cyber 830 mainframe computer.

RESULTS AND DISCUSSION

The number of plant species collected from the fifteen plot locations of Miller-Anderson Woods Nature Preserve can be seen in Table 1. Slight differences in the data are noted when compared to the previous published information of Monoson and Schertz (1985). In the present study, these differences are due to a particular taxon occurring in more than one sample plot.

Total plant taxa numbers varied according to the habitat (Table 1). Wooded lowlands and mesic regrowth along stream banks contained the highest numbers of different taxa recorded for the study. Presumably, abiotic and other ecological conditions in the two habitats contributed to the high number of plant species.

The Pearson chi-square (X^2) was 56.06 for the data in Table 1. This statistical test would follow a chi-square distribution with 28 degrees of freedom if sample plot and relative abundance were independent. Independence of the latter two variables was rejected since the X^2 exceeded even a 0.005 critical value of 50.99.

A 10-by-3 table was formed when sample plots formed from the same habitat were combined. The Pearson chi-square test statistic (X^2) was 45.22 for this table. Independence of habitat and relative abundance was rejected because the X^2 exceeded the 0.005 critical value of 37.16 for a chi-square distribution with 18 degrees of freedom.

The ordinal model provided a marginally satisfactory fit of the data. As there were ten habitats, the model used 21 parameters- one μ, nine λ_i's, two α_j's, and nine τ_i's. Parameter estimates were calculated and then the expected cell frequencies (m_{ij}'s) were determined. Expected and observed numbers per cell in the ordinal model can be seen in Table 2.

The goodness-of-fit test statistics, likelihood-ratio chi-square G^2 and Pearson chi-square X^2, were 38.63 and 40.95 respectively for Table 2. These statistics, under the null hypothesis of satisfactory fit, would have a chi-square distribution of 45-21 = 24 degrees of freedom. Thus, the ordinal model G^2 and X^2 have significance of approximately 0.035 and 0.02 respectively. While the ordinal model was only marginally acceptable, the alternatives of independence and further parameterization were unacceptable. The log-linear model of next higher complexity would have nine additional habitat parameters and would leave these habitats uniquely characterized by a single sample plot with zero degrees of freedom toward a chi-square test of satisfactory fit.

We also examined the null hypothesis that $\tau_i = 0$ for all i's in the ordinal model. The likelihood-ratio chi-square test of the null hypothesis yielded a G^2 of 26.44 based on 9 degrees of freedom. The null hypothesis was rejected because G^2 exceeded the 0.005 critical value of 23.59. Therefore, the inclusion of habitat-versus-relative-abundance interaction contributed significantly towards an adequate interpretation of the data.

Maintenance of separate parameters for northern and southern DMUF plateaus aided in the model-fitting process. Associating all of the DMUF plots with a single set of parameters would have added one to the degrees of freedom and more than six to the ordinal model's G^2.

The ordinal model predicted relative abundance for some habitat sample plots better than for others (Table 2). Observed and expected values were very similar for the WL, NEFS, and DOFS habitat plots. Conversely, the observed and expected values in the MR habitat plot were quite different. The MR plot with only one degree of freedom, out of 24 degrees of freedom in the ordinal model, contributed roughly 25 percent to the chi-square statistics. Exclusion of the MR plot would result in a more acceptable fit of the data to the model. The similarity or dissimilarity of the observed and expected plant relative abundance values were probably linked to ecological considerations in the different habitats. The validity of the different statistical parameters used in this investigation can be tested by their repeatability. At the present time, one can only speculate as to which of the abiotic factors was the main contributor to plant relative abundance in a particular habitat.

In summary, we believe that the ordinal model best explained the data. Habitat affected the number of observed species and their relative abundance tendencies. We think that future studies ideally should include two or more plots per habitat in the experimental design. Having multiple plots per habitat would assist in the evaluation of distribution patterns of species abundance within habitats.

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Table 1. Sample Plot by Frequency Category of Observed Species

	Abundance			
Habitat[a]	Rare[b]	Occasional[c]	Abundant[d]	Total
DMUF-North				
Plot 1	0	8	13	21
Plot 2	4	8	6	18
Plot 6	1	9	13	23
DMUF-South				
Plot 12	2	3	5	10
Plot 13	4	6	9	19
Plot 14	0	3	6	9
SEFS				
Plot 3	7	11	6	24
Plot 5	5	10	11	26
WL - Plot 4	17	43	19	79
NEFS - Plot 11	6	18	12	36
DOFS - Plot 7	3	19	17	39
MR - Plot 8	4	45	18	67
WOFS - Plot 9	1	17	8	26
SM - Plot 10	7	12	7	26
HP - Plot 15	8	19	6	33
Total	69	231	156	456

[a]DMUF = Dry mesic upland forest; SEFS = Southeast facing slopes; WL = Wooded lowlands; NEFS = Northeast facing slopes; DOFS = Dry old field succession; MR = Mesic regrowth along stream banks; WOFS = Wet old field succession; SM = Sedge meadow; HP = Hill prairie.
[b]<12 plants
[c]12-15 plants
[d]>25 plants

Table 2. Observed and Expected Relative Abundance Numbers Under the Ordinal Model

Habitat[a]	Rare[b]	Occasional[c]	Abundant[d]
DMUF - North			
Plot 1 observed	0	8	13
expected	1.36	8.94	10.36
Plot 2	4	8	6
	1.36	8.94	10.36
Plot 6	1	9	13
	1.36	8.94	10.36
DMUF - South			
Plot 12	2	3	5
	1.06	5.87	5.73
Plot 13	4	6	9
	1.06	5.87	5.73
Plot 14	0	3	6
	1.06	5.87	5.73
SEFS			
Plot 3	7	11	6
	4.54	13.43	7.04
Plot 5	5	10	11
	4.54	13.43	7.04
WL - Plot 4	17	43	19
	17.06	42.88	19.06
NEFS - Plot 11	6	18	12
	5.52	18.96	11.52
DOFS - Plot 7	3	19	17
	3.38	18.23	17.38
MR - Plot 8	4	45	18
	9.17	34.66	23.17
WOFS - Plot 9	1	17	8
	3.00	13.01	10.00
SM - Plot 10	7	12	7
	5.94	14.12	5.94
HP - Plot 15	8	19	6
	8.57	17.85	6.57

[a]DMUF = Dry mesic upland forest; SEFS = Southeast facing slopes; WL = Wooded lowlands; NEFS = Northeast facing slopes; DOFS = Dry old field succession; MR = Mesic regrowth along stream banks; WOFS = Wet old field succession; SM = Sedge meadow; HP = Hill prairie.

[b]<12 plants

[c]12-25 plants

[d]>25 plants

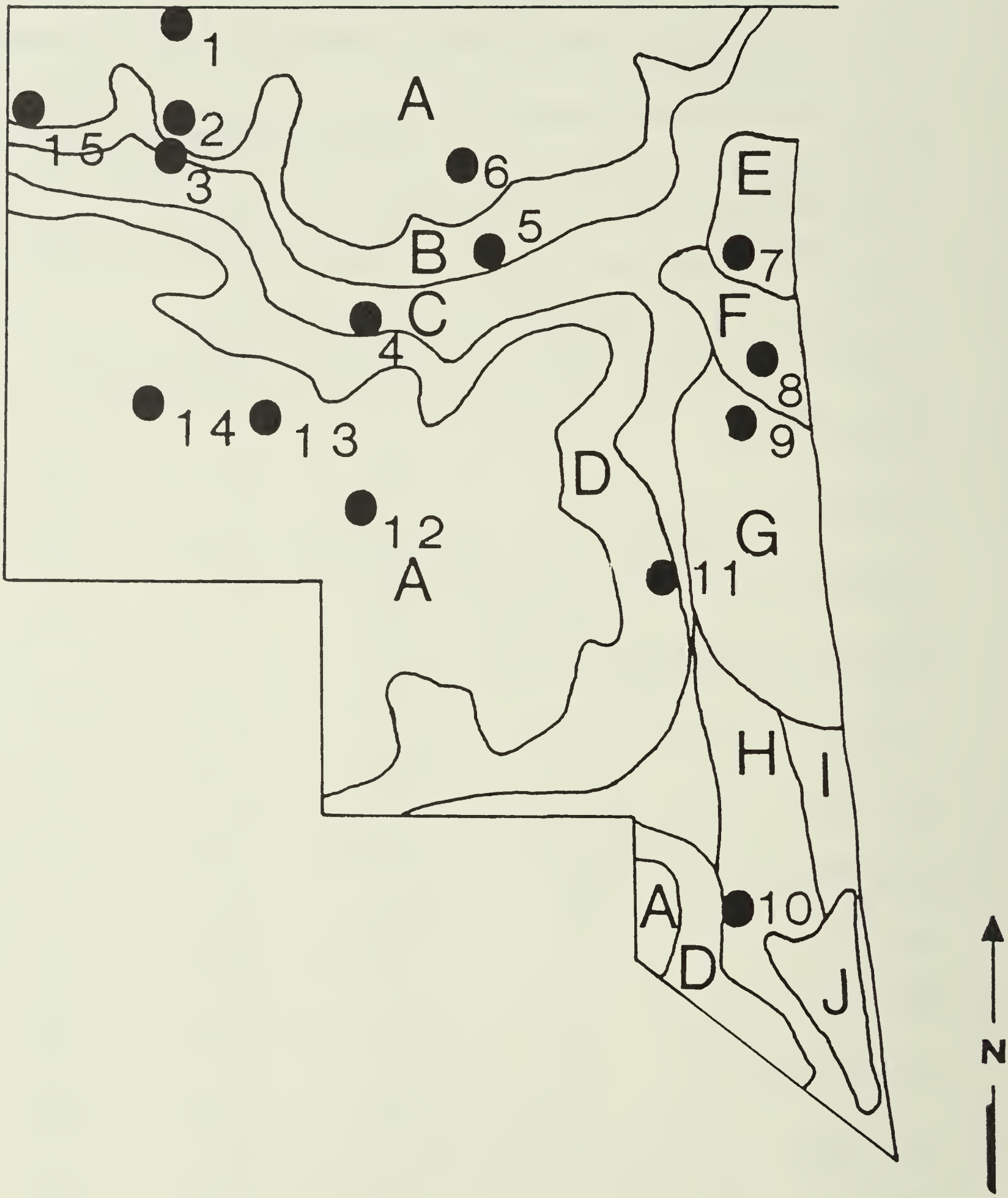

Figure 1. Habitats and plot numbers of Miller-Anderson Woods Nature Preserve. A. Dry mesic upland forest-1, 2, 6, 12, 13, 14. B. Southeast facing wooded slopes-3, 5. C. Wooded lowlands-4. D. Northeast facing wooded slopes-11. E. Dry old field succession-7. F. Mesic regrowth forest along stream banks-8. G. Wet old field succession-9. H. Sedge meadow-10. I. Regrowth area along new Illinois Route 29. J. Back water bog area. Hill prairie-15.

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THE NEED FOR A SYSTEMATIC LAKE SEDIMENTATION SURVEY PROGRAM IN ILLINOIS

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ABSTRACT

This article summarizes the history of lake sedimentation surveys in Illinois and the present state of surveying. Illinois possesses one of the longest lake sedimentation survey programs in the nation. However, at present no concerted effort is expended in the regular maintenance of a sedimentation survey program. Many Illinois lakes are losing their capacities at an alarming rate and some lakes will be almost useless as either recreational facilities or sources for public water supplies in the very near future. A regular and well-planned lake sedimentation survey program is essential for the better management of this important resource of the state of Illinois.

INTRODUCTION

Erosion and sedimentation are natural processes that can be neither stopped nor eliminated. However, when these processes become excessive they impact many human uses of water. Sedimentation in Illinois lakes and sediment transported by Illinois streams have been recognized as the major water resources problems in Illinois.

Knowledge of the existence and quantities of sediments in Illinois water affects a multitude of agency and business decisions. There are many gaps in our current knowledge of this area. For example, there are major questions with concerning the impact of sediment of stream biota and stream environment; on water treatment plants; lake sedimentation; locations and causes of sheet, gully, and stream bank erosion; and pollutants carried by sediment.

Illinois lakes serve as the major sink of the sediment and pollutants carried by streams. Rate of capacity loss of Illinois lakes must be measured directly and it is not a direct function of the amount of sediment transported by the streams. A quantification of the sedimentation rates in Illinois lakes will not only show the rate of capacity loss of the lakes, but may also indicate the relative changes in the sediment yield from the watersheds because of natural variations and/or human activities.

In 1982 over 33 billion gallons of water per day were used in Illinois. Surface water resources accounted for 97% of this total use, or approximately 32 billion gallons per day. Of this 32 billion gallons of daily water use, about 68% was used by hydroelectric facilities, 26% by thermoelectric power plants, 4% by public water supply utilities, and the remaining 2% by manufacturing, mining, and other users. In Illinois about 5.6 million people rely on surface sources for potable water. Approximately 1.1 million people receive their water from small lakes and reservoirs. Maintenance of the storage capacities of these lakes is thus extremely important for many municipalities, communities, and cities in Illinois.

In recognition of the importance of Illinois' lakes and the impairment of their condition due to sedimentation, Governor James Thompson issued a proclamation declaring April 1985 as Lake and Watershed Cooperation Month (Bhowmik et el., 1985). This proclamation stated in part that "Illinois' 2,900 lakes and 81,000 ponds provide inestimable economic and aesthetic benefits including drinking water, fishing, swimming, boating, cooling water for utilities and industry, and flood control; . . . the Illinois State Water Plan and the Water Quality Management Plan have identified soil erosion as the number one water resource issue facing Illinois and have documented the economic impacts of erosion on Illinois lakes."

This recognition of the close relationship between watershed erosion and sedimentation problems in both lakes and rivers reflects a growing concern about the quality and quantity of the water stored in Illinois lakes. It is essential that the state know the sedimentation rates of Illinois lakes in order to better manage its water resources.

History of Lake Sedimentation Surveys

In the early 1930s, realizing the potential impact of sedimentation on the state's surface water impoundments, the Illinois State Water Survey in cooperation with other interested agencies pioneered the use of lake sedimentation surveys in Illinois for evaluating the conditions of lakes. This program evolved from the Water Survey's long-standing involvement in investigating the quantity and quality of the state's water resources. Illinois may thus possess one of the longest lake sedimentation survey programs in the nation. Over the years, the Water Survey has accumulated records from approximately 180 surveys of more than 130 lakes in Illinois. Figure 1 shows the locations of these surveys. As can be seen, most of these lakes are located in the western and southern parts of the state where ground water either is not available or has not been exploited because of economical reasons. Approximately 15 backwater lakes along the Illinois River have also been surveyed. The original emphasis in the lake sedimentation surveys was on the capacity loss of the lakes due to sediment deposition. However, in recent years the program has been extended to include analyses of water and sediment quality as well as the sources of the sediment. This broadened scope is possible because of the various research activities performed in connection with the lake sedimentation surveys.

Results of the studies have shown that Illinois lakes are losing their capacities at the rate of 0.2% to 4% per year. Figure 2 is a plot showing capacity losses of Illinois lakes surveyed since 1930. At least 12 of these lakes are losing their capacities at a rate of more than 2% per year. If this rate continues, they will lose 50% of their capacities in about 25 years.

The Water Survey's lake sedimentation program was extremely active during the 1950s and early 1960s (figure 3). During this period, several major reservoir watershed studies were conducted in cooperation with other local, state, and federal agencies. However, since the mid-1960s the Water Survey's effort has been considerably reduced because of limited state support. As a matter of fact, during the period 1967-1970 and in 1973 not a single lake sedimentation survey was conducted in Illinois.

In recent years, the Water Survey has conducted sedimentation surveys either in cooperation with local communities or for specific research projects. Among the surveys in the first category are those for Decatur, Springfield, Mount Olive, Virginia, Vermont, Staunton, Vermilion, Taylorville, and Litchfield. Surveys within the research category include surveys of Lake Pittsfield, Highland Silver Lake, Horseshoe Lake in Alexander County, Mattoon Lake, and Lake Paradise. It should be pointed out that many of the communities that depend on lakes as their sole source of water realize the importance of sedimentation surveys and have cooperated with the Water Survey extremely well.

The future of lake sedimentation surveys in Illinois looks extremely bleak unless something is done fairly soon. Long-term sedimentation surveys must be recognized as essential in predicting the rate of capacity loss of Illinois lakes, and changes in those rates over time. It is quite possible that some lakes may show a trend of decreasing rate of capacity loss with time. Figure 4 shows the changes in capacity loss for two lakes in Illinois and a pool along the Mississippi River. It appears that the rate of sedimentation in Lake Decatur decreased from 140 acre-ft deposited sediment for the 10-year period from 1956 to 1966 to 120 acre-ft from 1966 to 1983, (Fitzpatrick et al., 1987). For the period from 1934 through 1948, Lake Springfield appeared to lose its capacity at a rate of 186 acre-ft per year, but from 1948 through 1977, the rate of loss was about 138 acre-ft per year. Moreover, most of the capacity loss of Lake Springfield occurred near the upstream areas of the lake, especially within the Lick Creek and Sugar Creek arms. The percent capacity loss of Lake Springfield from 1934 through 1984, by segments, is shown in Figure 5, (Fitzpatrick et al., 1985). Similar patterns of sediment deposition have been observed in many other Illinois lakes where the upstream end is gradually changing from a lacustrine environment to a palustrine-terrestrial environment. This type of transformation is taking place in Peoria Lake (Demissie and Bhowmik, 1987).

As is the case for most of the lakes, Pool 19 on the Mississippi River has shown a gradual decrease in capacity loss with time (figure 4). It has been predicted that Pool 19 will attain a dynamic equilibrium by the middle of the next century, when it will have lost about 58% of its original capacity (Bhowmik et al., 1986). This analysis points up the importance of long-term data collections and shows how these can help us to plan and manage our resources judiciously.

We must realize that the state needs to make definite commitments toward maintaining a viable and useful lake sedimentation survey program. The state should not and cannot depend on the cities, municipalities, and others to support a

sporadic program. It is almost certain that very few new lakes will be built in the near future, and thus the people of Illinois will have to depend on existing lakes for potable water. Existing lakes must be technically analyzed to determine their need and suitability for revitalization and rehabilitation.

It is suspected that if Illinois experiences a drought in the near future, many of the public water supply lakes will be dry and will not be suitable for use as sources of water. A regular lake sedimentation survey program can identify the lakes that are losing their capacities at the fastest rates. By predicting future lake capacities, such a program can sound the alarm long before lake capacity becomes a critical problem as a result of natural causes such as droughts.

RECOMMENDATIONS

On the basis of this evaluation, it is recommended that a regular lake sedimentation survey program be initiated by the state of Illinois with the following features:

- Surveying will be done by the State Water Survey
- A total of 5 to 10 lakes will be surveyed every year
- Repeat surveying will be done on a 10- to 15-year cycle
- Selection of the lakes for surveying will depend on past and projected sedimentation rates and on the importance of the lakes in terms of the number of people served, recreational facilities, etc.
- Input from state, local, federal, and public officials will be considered in the selection of the lakes to be surveyed.

The proposed program will also encompass the following: (1) impacts of temporal and spatial factors on sedimentation rates, (2) movement of sediment within riverine and lacustrine environments, and (3) impacts of hydrological, hydraulic, and geotechnical factors involved in sedimentation.

This proposed program has already been recommended and approved by the State Water Plan Task Force (Bhowmik et al., 1985). Lakes are one of the major resources of the state and they must be managed properly, especially when it is evident that they not only provide potable water to many communities and serve as outdoor recreational facilities, but that they also accumulate most of the waterborne materials in streams, including many chemicals utilized in agricultural practices. Quantification of lake capacities and determination of sediment quality of major Illinois lakes used for municipal, industrial and recreational water supplies and sources are essential for the development and implementation of proper management practices.

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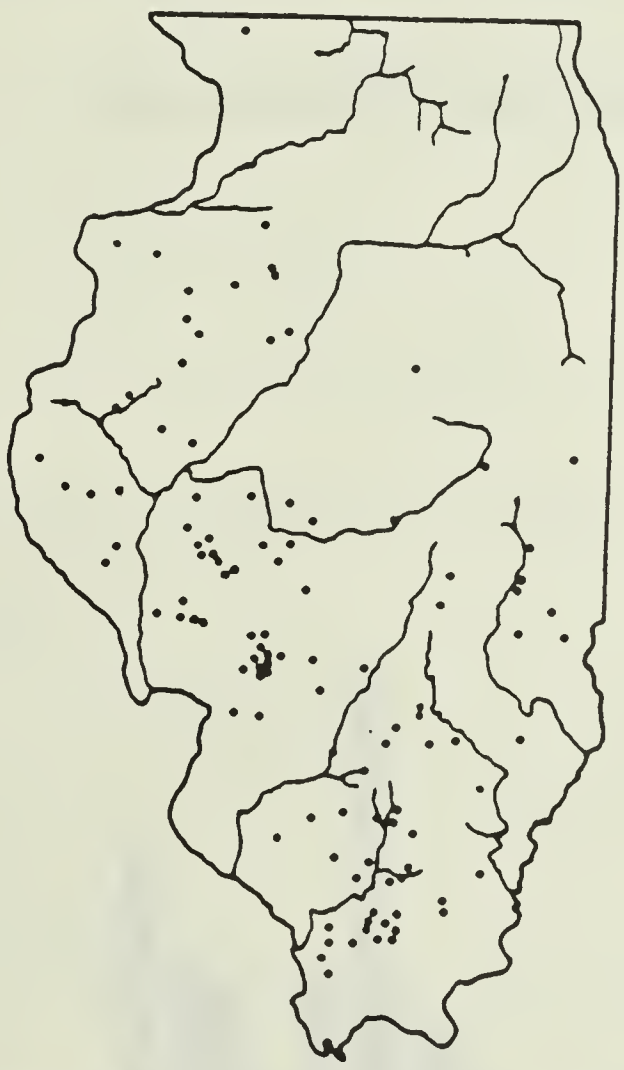

Figure 1. Locations of lake sedimentation surveys in Illinois

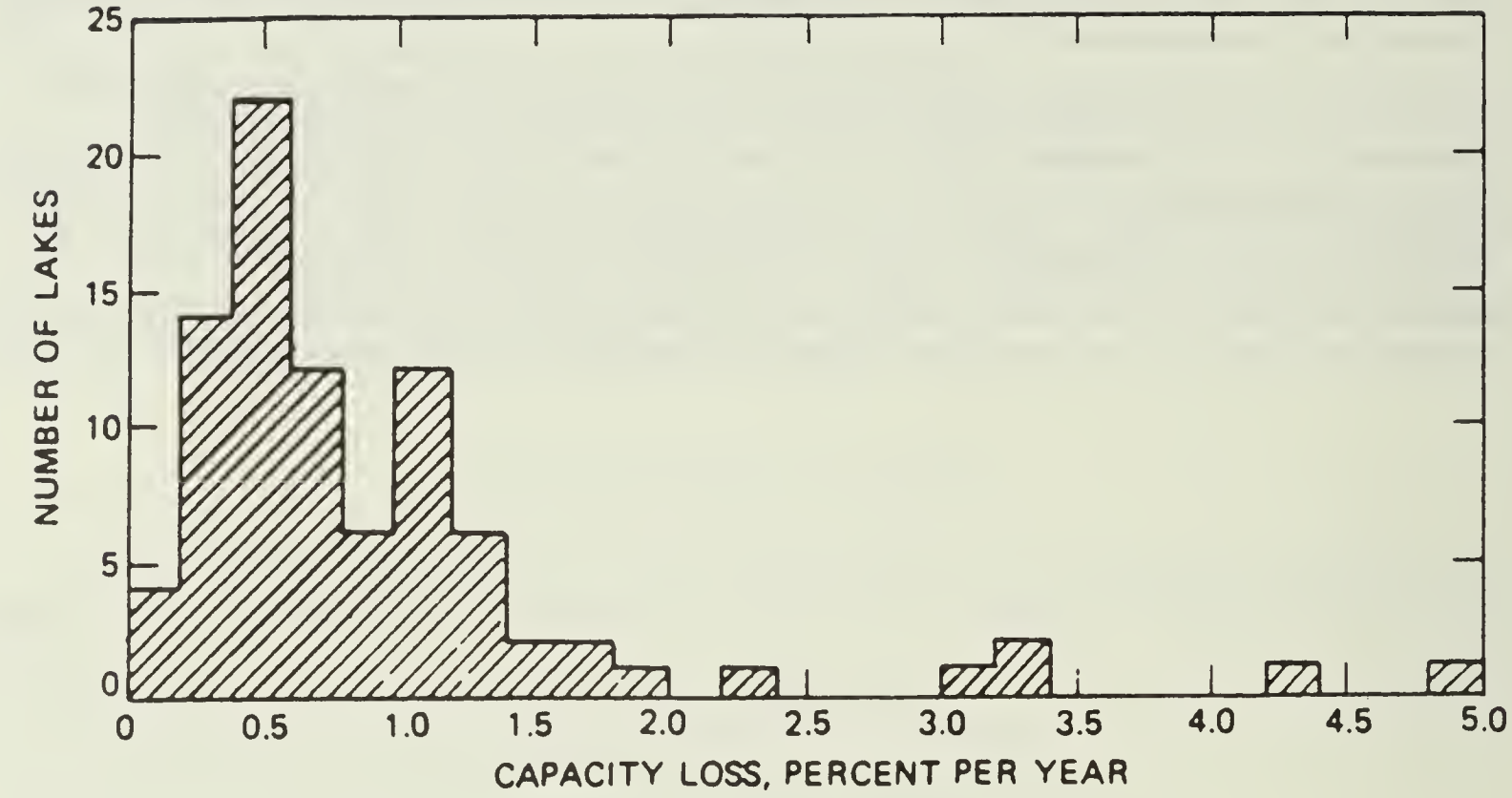

Figure 2. Capacity loss of Illinois lakes

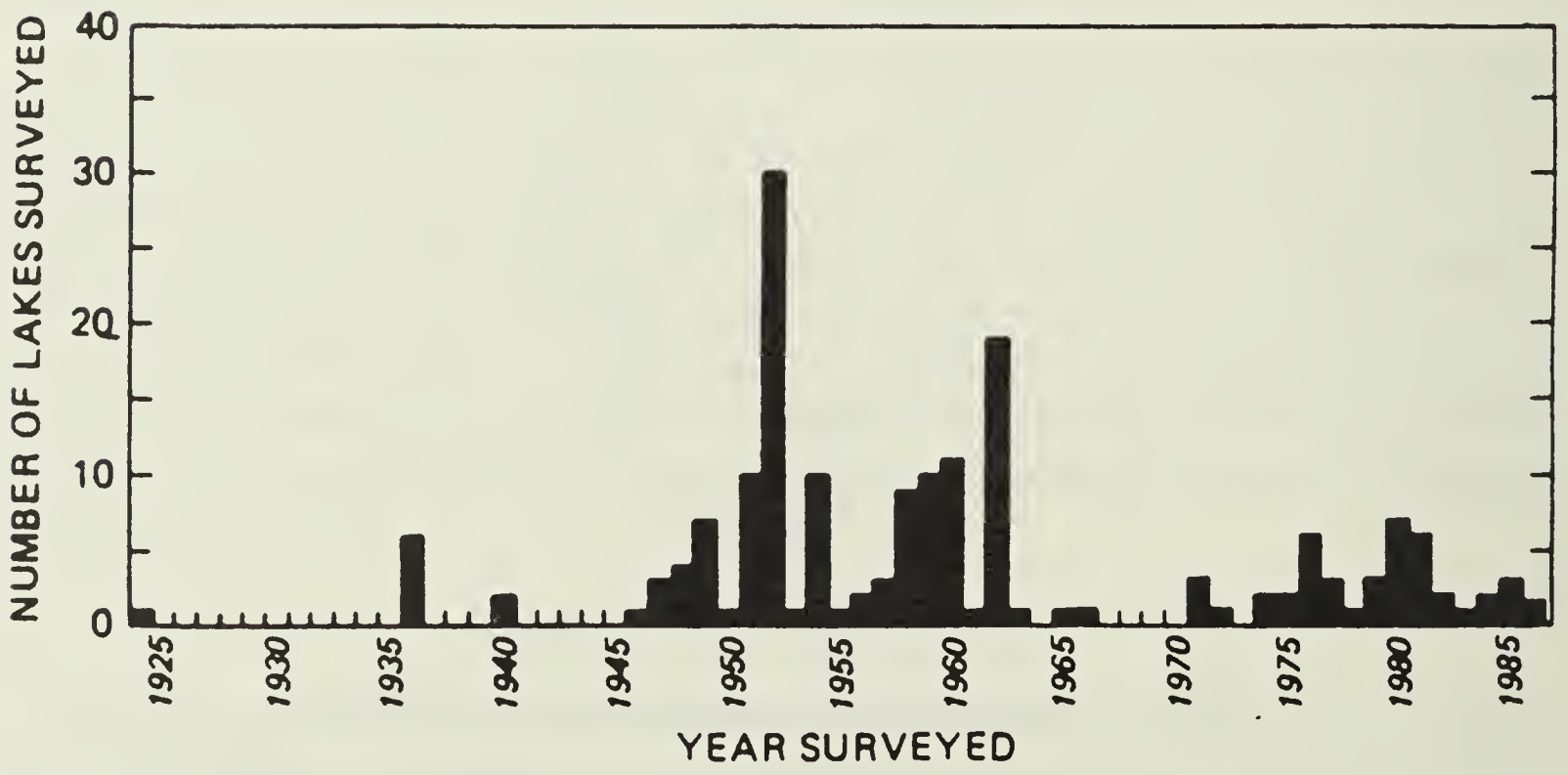

Figure 3. History of lake sedimentation surveys

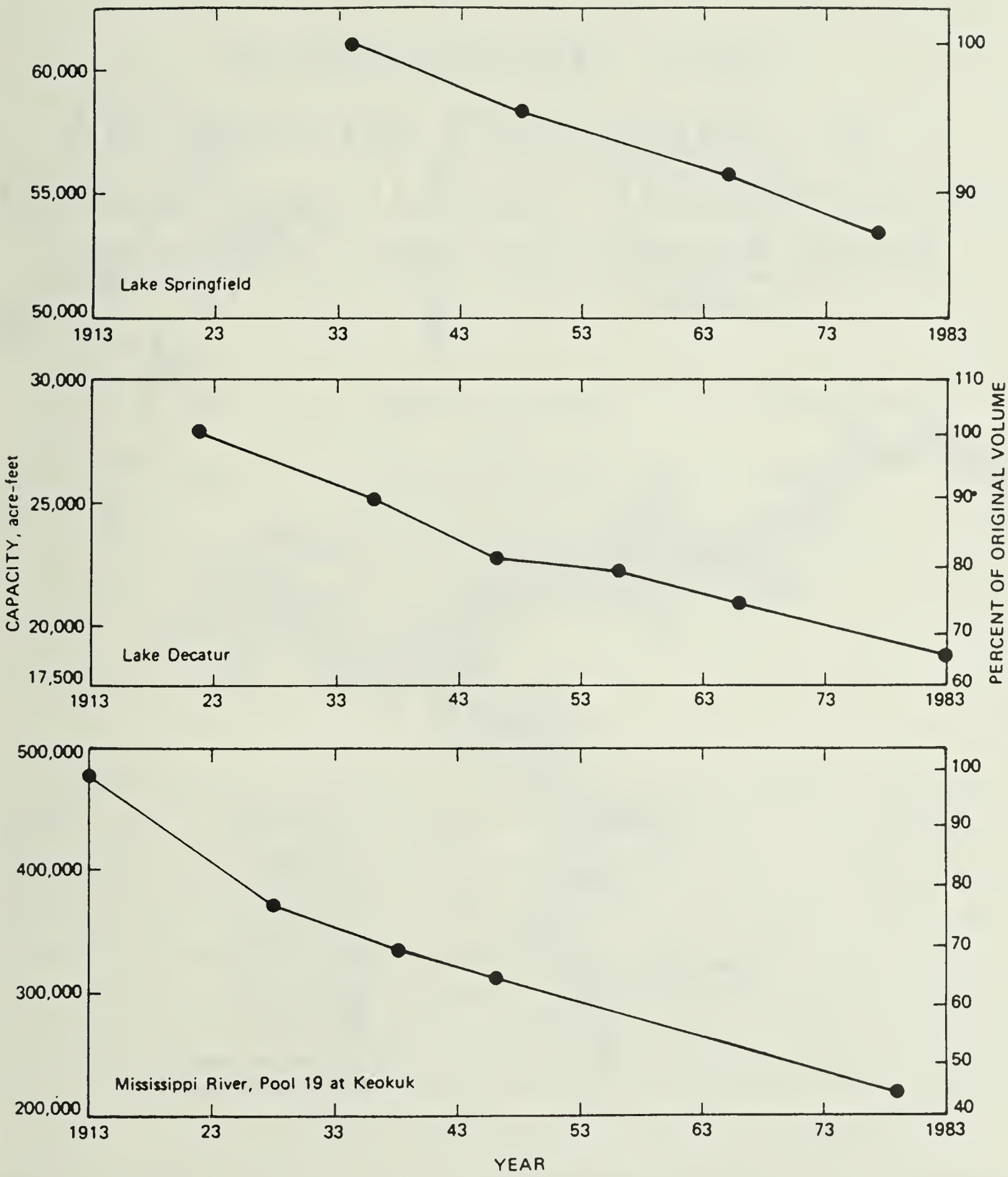

Figure 4. Capacity losses with time, Lake Springfield, Lake Decatur, and Pool 19, Mississippi River

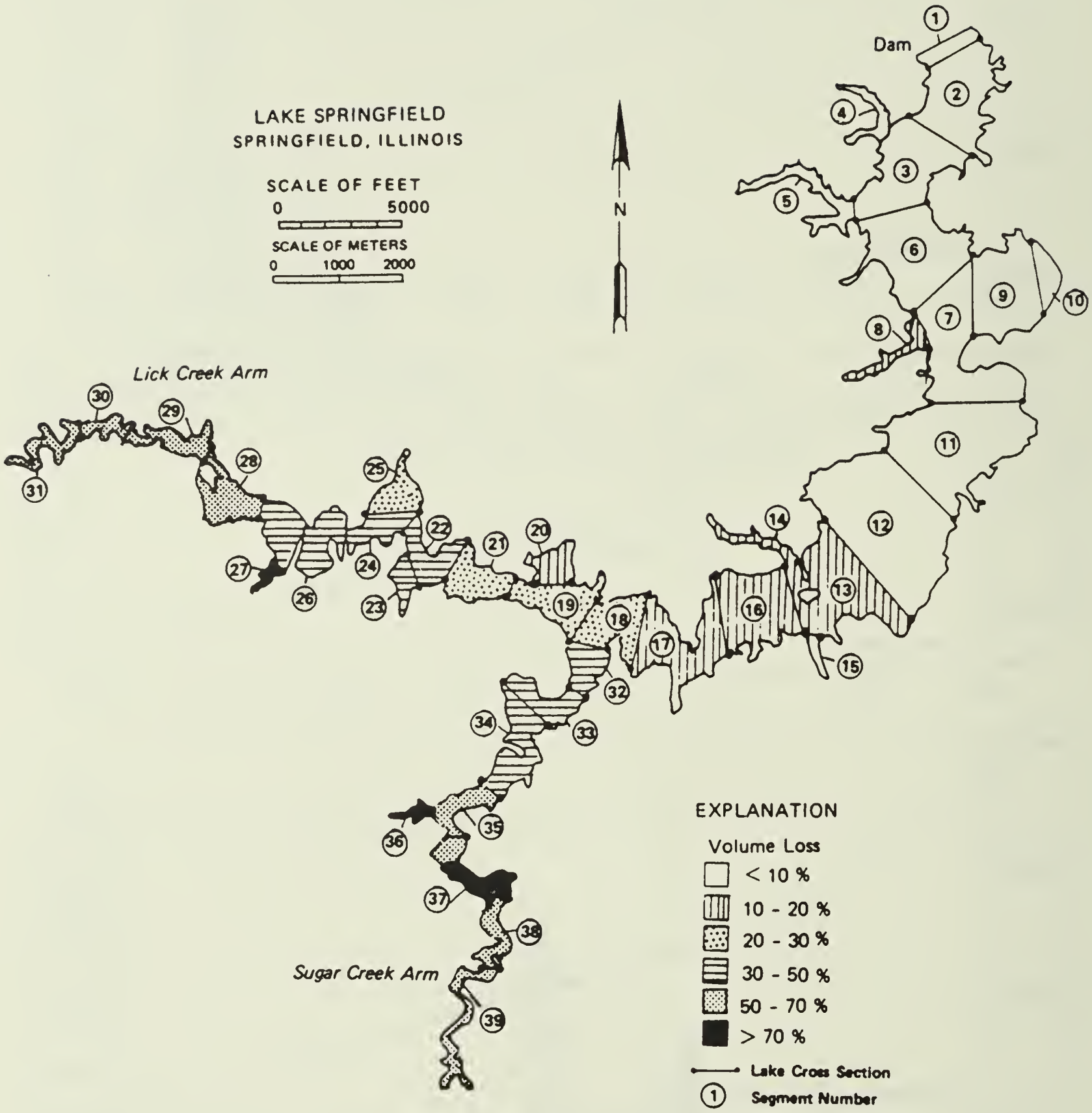

Figure 5. Percent loss of original volume in Lake Springfield due to sediment accumulation from 1934 through 1984, by segments

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PETROGRAPHY AND RESERVOIR PROPERTIES OF CHESTERIAN (UPPER MISSISSIPPIAN) ARENITES, SOUTHERN ILLINOIS

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ABSTRACT

Petrographic and petrophysical studies of oil- and gas-producing Chesterian arenites show no statistically significant stratigraphic distribution of petrographic types. Observed secondary porosity types are: corroded grains, honeycombed grains, moldic pores, moldic enlarged pores, oversized pores, elongate pores, and inhomogeneity of packing. These porosity types mainly originate from burial dissolution of calcitized feldspars and interstitial calcite cement. Two to three porosity types were selected to characterize each of the Chesterian arenites leading to their division into four major groups which coincide with variations of sorting. Group I includes the Aux Vases-Bethel-Ridenhower; Group II the Cypress-Hardinsburg-Tar Springs; Group III the Waltersburg-Palestine, and Group IV the Degonia. The direct correlation between sorting and types of porosity indicates that increased sorting enhanced the circulation of burial dissolving solutions. The proposed groups reflect only reservoir potentials which are not necessarily related to oil productivity.

INTRODUCTION

The Chesterian Series (Upper Mississippian) is widespread throughout southern Illinois and is characterized by cyclic alternations of limestone-shale formations

and sandstone-shale formations (fig. 1). Most of the sandstones are elongate bodies shaped as belts, dendroids, ribbons or pods, generally oriented NE-SW and cut into underlying formations. These bodies were produced by a deltaic distributary system of the ancient Michigan River (Potter et al., 1958; Potter, 1963; Swann, 1963; Willman et al., 1975). Today more than half of the oil in the Illinois Basin is produced from Chesterian sandstones, largely from the lower units, particularly the Cypress Sandstone (Swann and Bell, 1958).

These facts prompted this statistical investigation of the petrography, diagenetic evolution and generation of burial secondary porosity of these oil-producing sandstones. Previous fundamental studies by Siever (1953) and Potter (1963) established the relationships between petrology, sedimentary structures, and the environment of deposition of the Chesterian sandstones in the Illinois Basin.

MATERIALS AND METHODS

Samples were collected from the least weathered portions of outcrops in southern Illinois (fig. 2) due to the unavailability of sizeable subsurface cores for petrographic and porosity-permeability measurements. Comparison between the few available small cores and corresponding outcrop samples indicates that the sampling has avoided the major effects of weathering. Any error introduced by the effect of weathering in the porosity-permeability measurements would be 2%. Distribution (fig. 2) of the investigated 333 samples is as follows: Aux Vases: 30, Bethel: 36, Ridenhower: 5, Cypress: 34, Hardinsburg: 64, Tar Springs: 82, Waltersburg: 22, Palestine: 21, and Degonia: 39.

Thin sections of each sample were cut perpendicular to bedding and impregnated with blue low viscosity epoxy to reveal porosity. The petrographic investigation included: (1) determination of the maximum apparent grain size of quartz grains or clasticity index (Feiznia and Carozzi, 1987), (2) visual estimates of percentage of framework grains (quartz, feldspars and lithics), (3) of cement (quartz and feldspar overgrowths, calcite, dolomite, authigenic clay minerals, (4) of matrix (detrital clay minerals and hematite), and (5) of porosity.

A diameter ratio, which represents the inverse of sorting, can be estimated from the 16th and 84th percentiles of the grain size distribution, and 5 classes of sorting can be defined (Folk, 1974). In practice, a high degree of reliability of the estimation of the 16th and 84th percentiles is difficult to maintain and the average values of the estimates represent in reality the diameters in mm of the 10th and the 90th percentiles. These conditions allow to establish only 3 classes of sorting: well sorted (1.6-2.0 mm), moderately sorted (2.0-4.0 mm), and poorly sorted (4.0-16.0 mm).

Porosity and permeability were measured with Ruska equipment on plugs drilled as close as possible to each thin section. Porosity terminology is after Schmidt and McDonald (1979). Location of sampled sections, detailed descriptions of the thin sections, measurements of porosity and permeability, and description of the multivariate correlation program used to establish the possible relationships between measured petrographic and textural parameters and occurrence and types of secondary porosity are found in Ou (1984).

RESULTS

Petrographic Classification

Chesterian arenites belong, on the basis of framework grains, to four major petrographic groups using the classification of Williams et al. (1954). The following rock types have been identified: quartz feldspathic arenites, feldspathic arenites, subfeldspathic lithic arenites, and lithic arenites. The first three being by far the most common. No statistically significant distribution of these petrographic types among the nine Chesterian arenites was recognized.

Petrographic Components

Quartz is the dominant framework grain in all the types of arenites except the rare lithic arenites. It commonly displays undulose extinction, syntaxial overgrowth, and marginal replacement of original grains and overgrowths by calcite cement. Feldspar is the second abundant framework grain represented in decreasing order of importance by orthoclase, microcline and albite, all of which may display syntaxial overgrowth. Sericitization of potassic feldspar and plagioclase ranges from sericite flakes scattered randomly or concentrated along cleavage planes to complete replacement by sericite aggregates. Kaolinitization of potassic feldspar although not so common as sericitization, completely destroys individual grains converting them into vermicular aggregates. Calcite replacement of all feldspar types is common, ranging from marginal replacement to skeletal grains, and upon completion to euhedral patches of microgranular calcite cement. Accessory components are zircon, tourmaline, and muscovite flakes often distorted and split between more rigid framework grains.

Lithic grains in order of decreasing importance are: microcrystalline quartz ("chert"), metaquartzite, calcareous siltstone, hematitic siltstone, shale-claystone, micaschist, and dolomite. X-ray diffraction shows that the matrix consists of hematite-stained illite and mixed layer illite-smectite.

This study indicates that the mesogenetic sequence of cementation is the following. In a first phase, pressure solution of quartz and feldspar grains preceded interlocking quartz and feldspar overgrowths leading locally to quartzitic texture. In a second phase, carbonatization by precipitation of interstitial calcite cement with mosaic to poikilotopic texture and extensive calcitization of feldspars was followed by illite-smectite and illite-sericite precipitation as films with fibrous structure perpendicular to surfaces of growth. In a third and last phase, decarbonatization took place by dissolution of calcite cement and calcitized feldspars associated with direct dissolution of feldspars.

Porosity Types

With the exception of rare instances of primary interparticle porosity reduced by incomplete overgrowth on quartz and feldspar, most of the visible porosity is secondary, generated by burial processes, and consists of the following types: corroded grains, honeycombed grains, moldic pores, moldic enlarged pores, oversized pores, elongate pores and inhomogeneity of packing.

Corroded grains (fig. 3, A,B) result from marginal dissolution of original boundaries or overgrowths on both quartz and feldspar grains, directly or after partial replacement by calcite. Honeycombed grains (fig. 3, A,B,C) result from the

partial selective dissolution mainly along microperthitic intergrowths of potassic feldspars either fresh or previously altered to kaolinite or sericite, generating a typical skeletal aspect. Lithic grains are rarely affected by this process.

Moldic pores correspond to feldspar grains which have been completely dissolved, directly or after calcitization, leaving a peripheral film of clay minerals or hematite (fig. 3, C,D,F). In feldspathic arenites, quartz overgrowth is a predominant process of cementation which develops euhedral faces often penetrating adjacent softer feldspar and lithic grains. Consequently moldic pores display either the euhedral subrectangular shape of feldspar grains or its combination with other straight margins corresponding to penetrating quartz overgrowth faces. Complex polygonal pores are thus generated. Moldic enlarged pores (fig. 3, E,F) derive from moldic pores which were further enlarged so that the dissolution of feldspar grains also involved overgrowths or detrital cores of adjacent quartz grains. Therefore the shape of these pores becomes more irregular associating straight and random margins. Oversized pores originate mainly from the dissolution of two or more adjacent feldspar grains directly or after calcitization with possible extension into the overgrowths or detrital cores of surrounding quartz grains (fig. 3, G). A second possibility is by dissolution of adjacent feldspar grains and surrounding patches of calcite cement (fig. 3, H). The shape of these pores becomes extremely variable, ranging from rectangular when a row of grains are dissolved to a combination of random margins and straight faces. Elongate pores (fig. 3, I), in places quite abundant, result from the uniform marginal replacement of quartz and feldspar grains with or without overgrowths, by calcite cement along irreducible lamellar pores, followed by dissolution of the carbonate.

Inhomogeneity of packing (fig. 3, J) results from tightly-packed grains of quartz and feldspar cemented by pressure solution and overgrowth and other patches where no overgrowth or an incipient one have left interstitial spaces filled by calcite cement. This peculiar texture is often related to bioturbation processes. Subsequent dissolution of the carbonate generates irregularly distributed pores with straight to curved margins depending on the amount of overgrowth on adjacent grains.

DEPOSITIONAL AND DIAGENETIC INTERPRETATION

Two to three porosity types where chosen to characterize each of the nine investigated arenites leading to their division into four major types (table 1). Mean figures are also given for the major compositional and textural parameters such as: clasticity index, feldspar content, quartz and feldspar overgrowth, lithic grains content, matrix content, and diameter ratio (inverse of sorting). The relative uniformity of composition of all investigated Chesterian arenites previously shown by the absence of statistically significant distribution of petrographic types is also confirmed by the multivariate correlation program (see Ou, 1984). The program indicates no significant correlation between petrographic parameters and occurrence and types of secondary porosity, but a significant correlation with a textural parameter, namely the diameter ratio expressing sorting. The four variations of sorting correspond to the four major types based on porosity. Given the uniformity of all other parameters there is a direct correlation between sorting and types of

porosity. This correlation indicates that increased sorting enhanced the circulation of the burial solutions which dissolved feldspars and calcite cement.

This study leads to a final interpretation (table 1) which divides the formations into four groups. Group I includes the Aux Vases, Bethel and Ridenhower Formations which have the following features: poor sorting, predominant honeycombed porosity with some corroded grains and oversized pores, average measured porosity of 8.55 to 10.00%, average measured permeability of 0 to 24.51 md. The Bethel Sandstone is the coarsest Chesterian arenite (Willman et al., 1975).

Group II includes the Cypress, Hardinsburg and Tar Springs Formations which have the following features: moderate sorting, honeycombed porosity enhanced by oversized and moldic porosity, average measured porosity of 14.78 to 15.12%, average measured permeability of 6.71 to 38.98 md. Within this group the association of three types of porosity characterizes the Cypress which has a corresponding good permeability.

Group III includes the Waltersburg and Palestine Formations which have the following features: good sorting, predominant oversized porosity enhanced by moldic and honeycombed porosity, average measured porosity of 12.77 to 17.67%, average measured permeability of 11.13 to 88.38 md. Within this group the Palestine Sandstone has the highest values of measured porosity and permeability of all Chesterian arenites. It displays the best pattern of prograding deltaic deposits (Potter, 1963).

Group IV consists of the Degonia Formation which has the following features: moderate sorting, predominant moldic porosity enhanced by honeycombed and oversized porosity, average measured porosity of 14.58%, average measured permeability of 54.58 md.

CONCLUSIONS

The proposed division of Chesterian arenites in four major groups based on the association of their types of secondary porosity and sorting reflects only their reservoir potential which does not necessarily coincide with their oil productivity. Indeed, the latter is a function of numerous other geological criteria such as migration paths, extent and shape of the arenite bodies, stratigraphic or structural traps and thickness of pay zones, which are beyond the scope of this study. This study confirms that the Cypress Sandstone could be a prolific producer, and it is indeed the most important producing sandstone over its entire extent (Swann and Bell, 1958). The Tar Springs Sandstone and the Waltersburg Sandstone appear as potential moderate producers. This is generally true, although they can be very good locally in small fields where productive thicknesses may reach 18 to 21 m, the greatest of any of the Basin's sandstones (Swann and Bell, 1958). Finally, oil production from the Palestine Sandstone and the Degonia Sandstone, which would appear to be potentially excellent producers, is minor, almost entirely confined to the immediate vicinity of faults, and has little correlation with their distribution (Swann and Bell, 1958).

ACKNOWLEDGMENTS

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Department of Geology of the University of Illinois through the Exxon Education Foundation. Thanks are due to Ms. Beverly J. Seyler of the Oil and Gas Division of the Illinois State Geological Survey for advice on collecting localities, to Dr. Ralph L. Langenheim, Jr. for critical reading and constructive discussions, and to two anonymous readers.

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Table 1. Petrographic parameters, major porosity types, and porosity-permeability values of Chesterian arenites.

	Formation	C	F	OG	L	M	DR	Major porosity types in decreasing importance			AVP	AMP	AMK
								1	2	3			
IV	Degonia	0.40	17.73	f-c	7.73	6.36	3.01	moldic	honeycombed	oversized	15.45	14.58	54.58
III	Palestine	0.41	17.62	f-c	5.71	6.43	1.8	oversized	moldic	honeycombed	19.05	17.67	88.38
	Waltersburg	0.41	10.23	f	6.59	7.27	2.02	oversized	moldic	honeycombed	12.50	12.77	11.13
II	Tar Springs	0.40	17.11	f-c	9.56	7.44	2.87	honeycombed	oversized	_____	15.00	14.89	6.71
	Hardinsburg	0.36	15.26	f-c	8.73	6.02	2.51	honeycombed	oversized	_____	15.00	15.12	29.07
	Cypress	0.40	16.21	f-c	8.10	5.86	3.58	oversized	honeycombed	moldic	14.66	14.78	38.98
I	Ridenhower	0.35	19.00	c	12.0	10.0	4.22	honeycombed	corroded	_____	11.00	10.00	N.A.
	Bethel	0.63	13.19	c	7.36	6.39	4.50	honeycombed	corroded	_____	9.44	9.81	24.51
	Aux Vases	0.40	17.86	f-c	8.81	6.67	4.09	honeycombed	oversized	_____	10.71	8.55	1.47

C: clasticity index (mm); F: feldspar content (%); OG: quartz and feldspar overgrowth, (f = frequent, c = common); L: content of lithic grains (%); M: matrix content (%); DR: diameter ratio (inverse of sorting); AVP: average visual porosity (%); AMP: average measured porosity (%); AMK: average measured permeability (md)

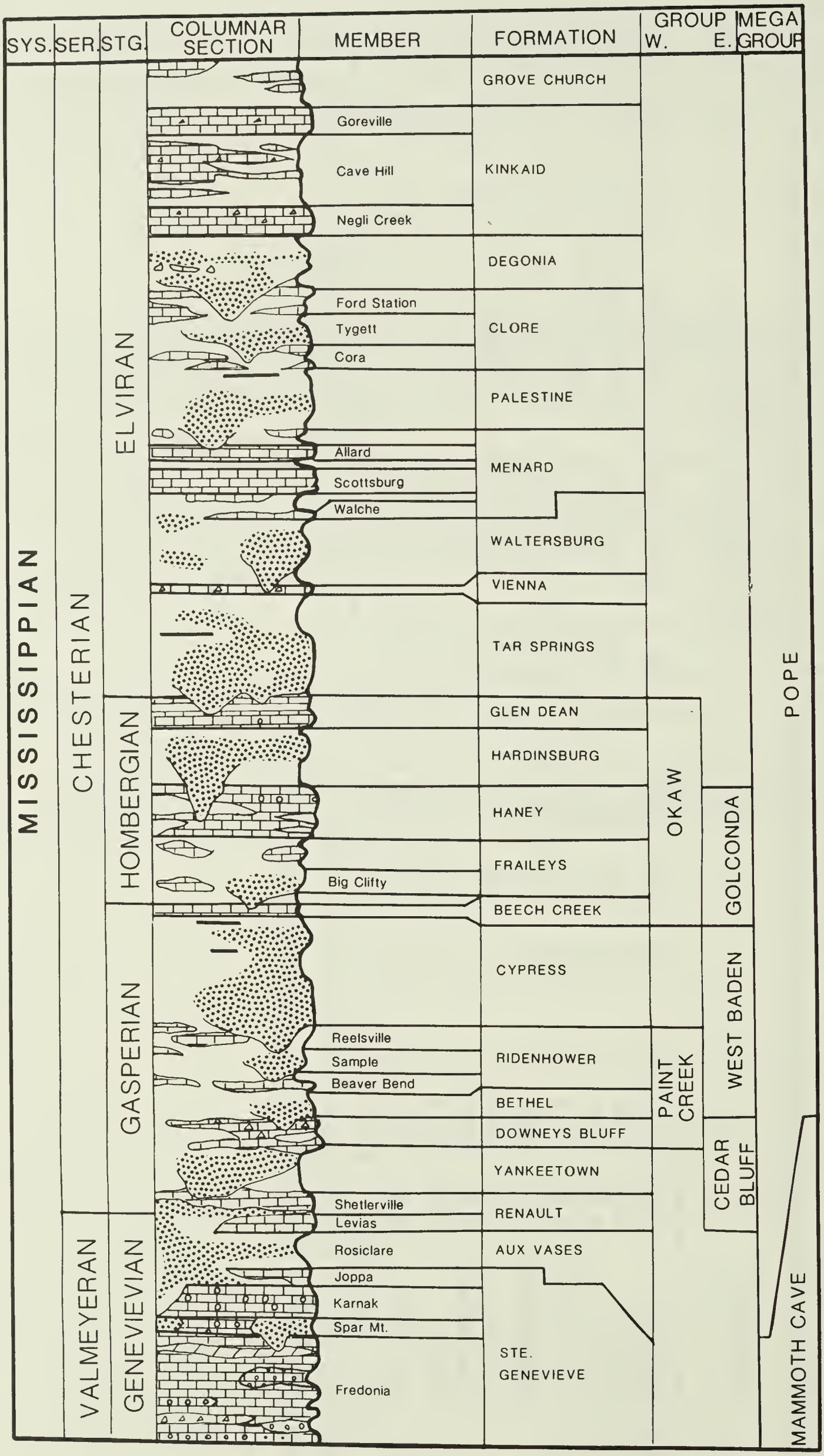


Fig. 1. Stratigraphic column of the Chesterian Series. Blank areas in columnar section are shales (modified from Willman et al., 1975).

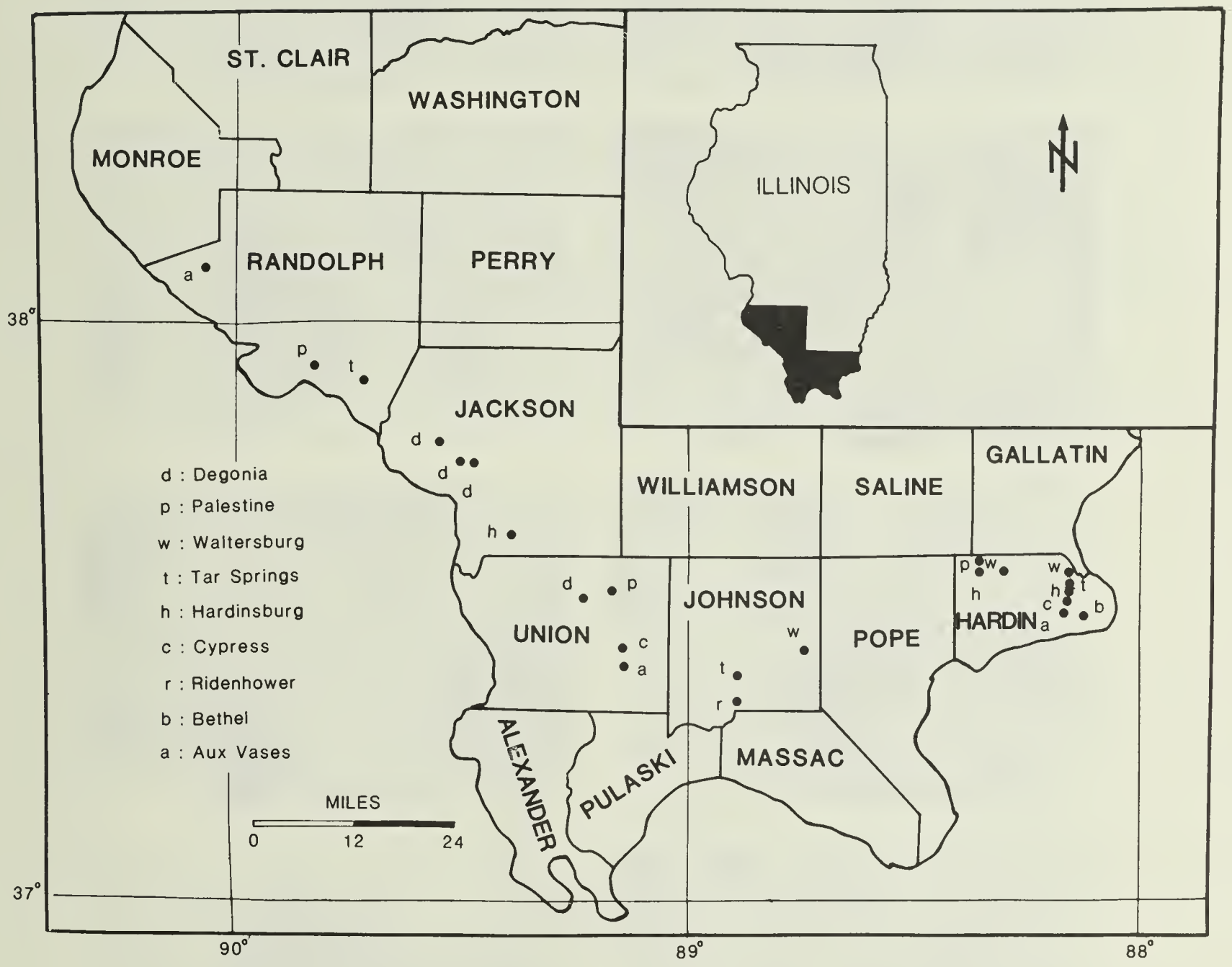
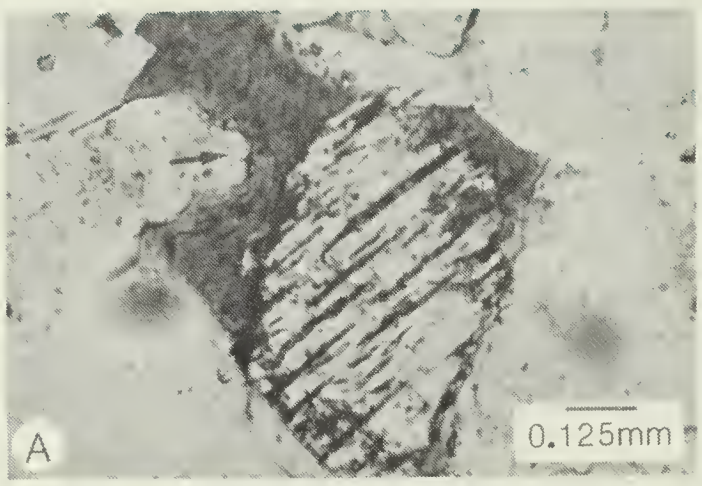


Fig. 2. Location map of sampled sections.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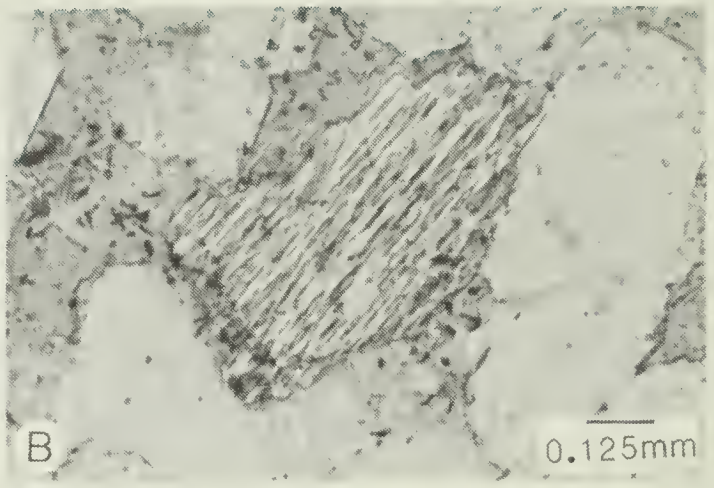
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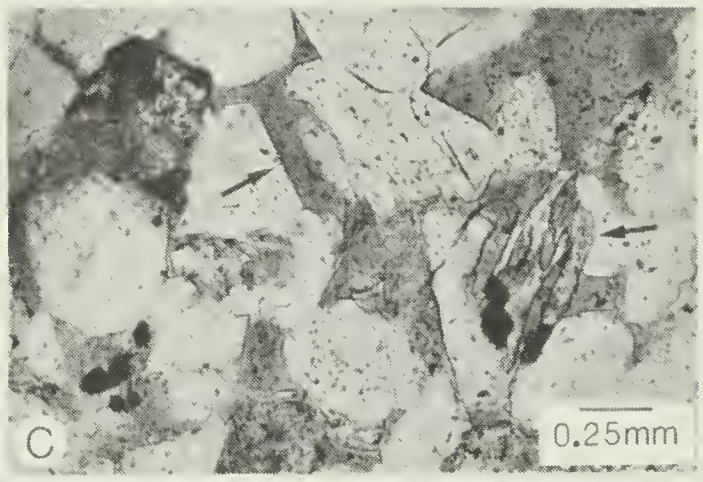
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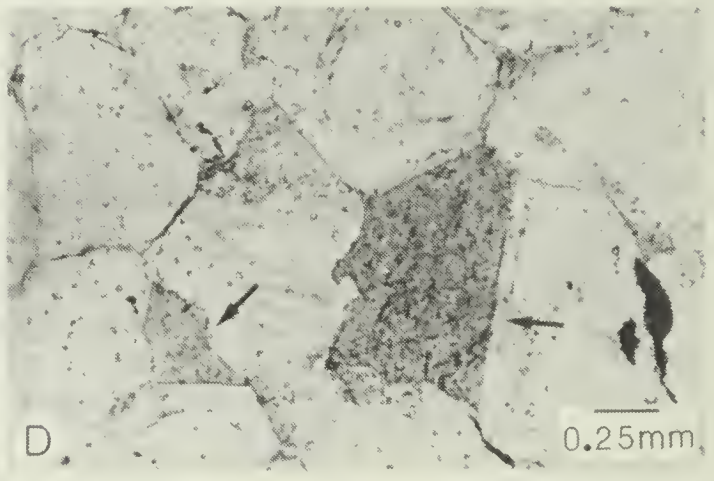
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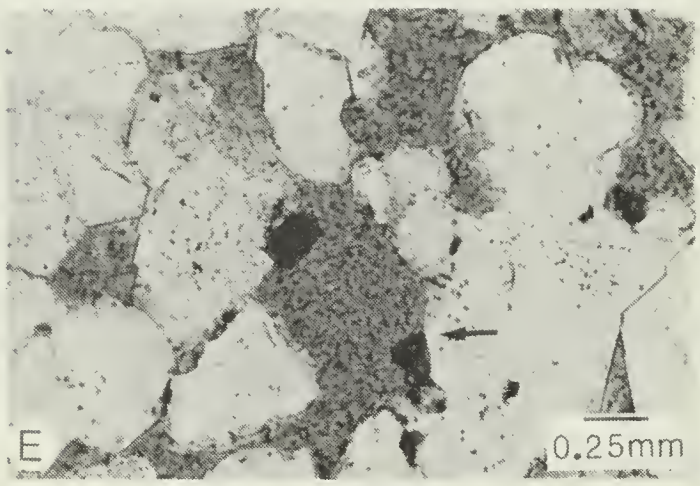
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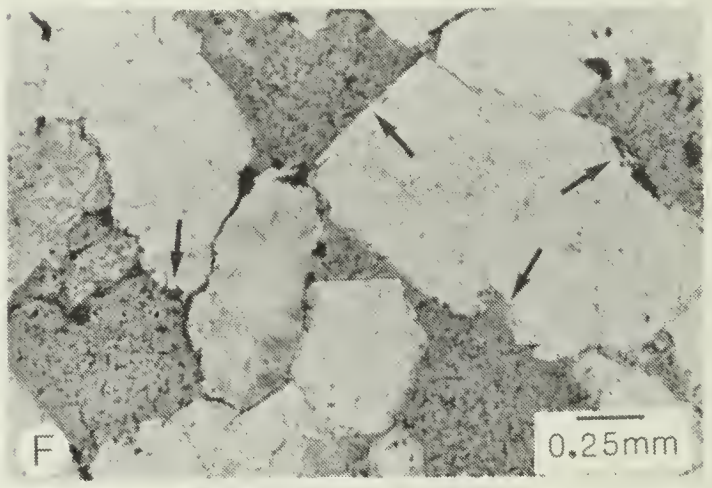
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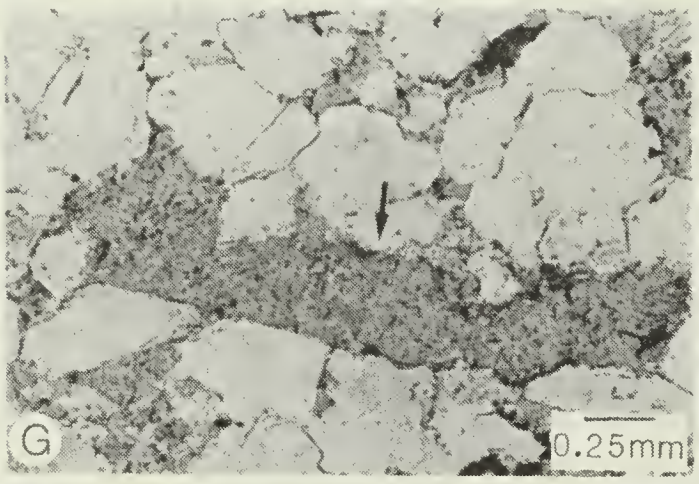
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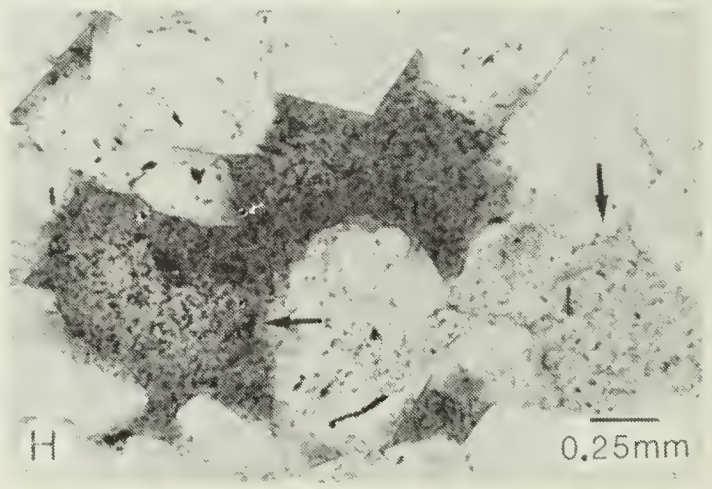
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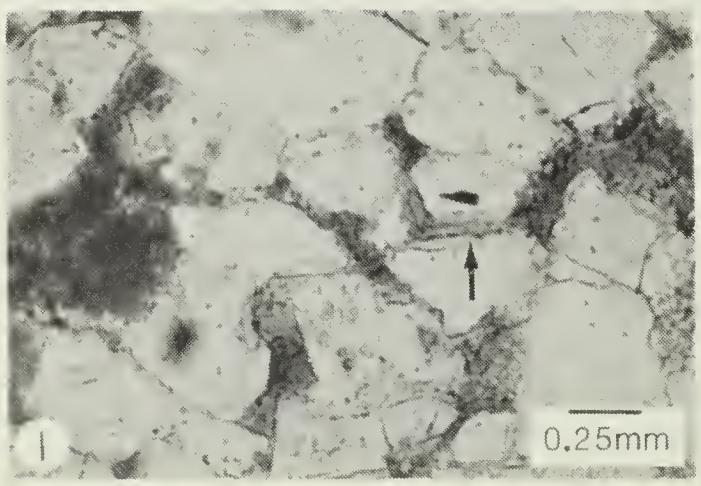
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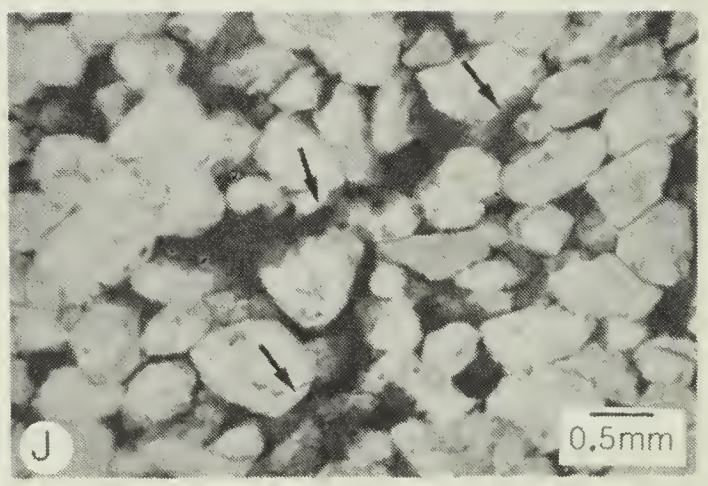
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Fig. 3. Porosity types. All photomicrographs in plane polarized light, porosity appears dark.

A. Honeycombed porosity from differential dissolution of microperthitic orthoclase grain. Upper left quartz grain (arrow) shows deeply corroded margins. Hardinsburg Sandstone.

B. Honeycombed porosity from differential dissolution of microperthitic orthoclase grain. All the surrounding quartz grains display corroded margins at the expense of their nuclei or overgrowths. Hardinsburg Sandstone.

C. Honeycombed orthoclase grain (right arrow) and small moldic pore with straight margin due to adjacent quartz overgrowth (upper left arrow). Degonia Sandstone.

D. Moldic pores from dissolved feldspar grain (right arrow) and from lithic grain (left arrow), both with partial straight margins from adjacent quartz overgrowths. Tar Springs Sandstone.

E. Moldic enlarged pore (arrow) with random margins predominant over straight ones. Hardinsburg Sandstone.

F. Moldic pore (lower left arrow) and three moldic enlarged pores (upper center and right arrows) from dissolved feldspar grains. Waltersburg Sandstone.

G. Oversized pore (arrow) from dissolution of three adjacent feldspar grains. Cypress Sandstone.

H. Oversized pore with feldspar residue (center arrow) from dissolution of three feldspar grains and calcite cement. The complex shape of the pore combines straight margins of feldspar grains with pyramid of quartz overgrowth and rounded outline of detrital quartz grain. Hardinsburg Sandstone.

I. Elongate pore (arrow) outlined by partially dissolved quartz overgrowths. Tar Springs Sandstone.

J. Inhomogeneity of packing with very irregular pores by dissolution of calcite cement (arrows). Hardinsburg Sandstone.

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IMPACT OF DOLOMITE AND SHALE SPOIL MATERIALS ON ILLINOIS WATER QUALITY: LABORATORY STUDIES

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ABSTRACT

The proposed construction of a Superconducting Super Collider (SSC) in north-west Illinois will generate approximately 1.5 million cubic meters of rock spoil material. Laboratory extraction experiments were conducted to investigate the potential impact of storage or land disposal of the predominantly dolomite and limestone spoil materials on water quality.

The major constituents in 39 water extracts generated by samples of likely spoil materials were Ca, Cl, K, Mg, Na, Si, and SO_4. Total organic carbon content in the extracts ranged from less than 0.05 to 9.06 mg/L. For all extracts, mean constituent concentrations were below drinking and surface effluent discharge standards. Selected spoil samples subjected to RCRA criteria were found to be nonhazardous. Solubility modeling of the water extracts predicted calcite as the prevalent mineral controlling the solubility of some constituents. Laboratory extraction and modeling studies suggest that the *in situ* leachates generated by the spoil material would be relatively innocuous, having no adverse effect on local surface and groundwater sources.

INTRODUCTION

It has been proposed that a Superconducting Super Collider (SSC) be constructed in northwestern Illinois. Construction of this underground facility will generate spoil rock material that would be stored or disposed at ground surface facilities (i.e., abandoned dolomite quarries and/or gravel pits). In order to plan for use, storage and disposal scenarios of the spoil materials that will protect water

supplies, it is necessary to assess the relative solubility of any potential pollutants in the solid waste. Laboratory extraction studies were conducted to evaluate the prevalent extractable constituents in the spoil materials.

Geologic studies (Kempton et al. 1985, 1986, 1987) have indicated that the SSC facility will be housed in a tunnel constructed principally in the Galena-Platteville Dolomite Groups, located approximately 122 m (400 ft) below land surface. Approximately 1.5 million cubic meters (m^3) of spoil rock material would be excavated from the tunnel. Curran (1986) estimated the spoil would consist of by volume: 2.6% (40,404 m^3) glacial till, 0.3% (4,527 m^3) sand and gravel, 3.0% (45,110 m^3) shale, 18.9% (290,756 m^3) limestone, and 75.3% (1.1×10^6 m^3) dolomite.

Alternative uses other than long-term storage of the predominantly dolomitic spoil include concrete aggregate, fill in construction projects, and the reconstruction of the Kaneville Esker in Kane County. The shale material has been used as a liner in waste disposal pits as well as fill (Kolata, 1986). Unless markets or special uses are found, permanent disposal or long-term storage of the spoil is likely. In any event, because much of the material will be placed at land surface locations, environmental study of the spoil is warranted.

MATERIALS AND METHODS

During an investigation to describe the geology of the proposed SSC tunnel site by the Illinois State Geological Survey (Kempton et al. 1985, 1986) seventeen 4.76-cm (1.88-in) diameter cores were collected in Cook, DeKalb, Du Page, Kane and Kendall Counties. These cores were selected because they represent the stratigraphic units that would be excavated and encompass the proposed tunnel site. Thirty-nine samples were collected from these cores and subjected to laboratory extraction studies. These samples represent the seven major lithologies that would be excavated during tunnel construction. These stratigraphic units and representative lithologies include: (1) Galena Group, Wise Lake Formation, dolomite; (2) Galena Group, Dunleith Formation, dolomite; (3) Galena Group, Wise Lake Formation, limestone; (4) Maquoketa Group, dolomite; (5) Maquoketa Group, shale; (6) Silurian formations (undifferentiated) dolomite; and (7) Platteville Group, dolomite (Fig. 1).

The American Society for Testing and Materials (ASTM) water shake extraction procedure was used as a rapid means of obtaining a solution for the evaluation of the water extractable materials from a solid sample (ASTM, 1982). The U.S. EPA Toxicity Characteristic Leaching Procedure (TCLP) determined if the spoil materials would be considered hazardous under U.S. EPA extraction procedure toxicity guidelines (U.S. EPA, 1986).

A Jarell-Ash Model 975 inductively coupled argon plasma spectrometer was used to determine the concentrations in solution of Al, As, B, Ba, Be, Ca, Cd, Cr, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, P, Pb, Sb, Se, Si, Sn, V, and Zn. Chloride and sulfate were measured by a Dionex 2110i ion chromatograph. Oxidation-reduction potential (Eh), pH, and electrical conductance (EC) were measured by electrode. Total organic carbon (TOC) concentrations were ascertained using a Dohrman DC-80 carbon analyzer. Refer to Krapac et al. (1984) for a listing of detection limits.

RESULTS AND DISCUSSION

Results of the ASTM shake test indicated that all extracts were alkaline with pH values ranging from 7.60 to 10.1. Of the 27 constituents analyzed for in the extracts, only nine constituents (B, Ba, Ca, Cl, K, Mg, Na, Si, and SO_4) were at concentrations greater than analytical detection limits. The average concentrations of these analytes indicated that the trend in concentrations was $SO_4 > Mg > Ca > Na > Cl > K > Si > B > Ba$ (Table 1). However the large standard deviation of such analytes as SO_4 and Na suggest large variations in concentrations between the various samples. Evaluation of constituent concentration in extracts generated by the same solid sample lithology resulted in a general ranking of $Mg > Cl > SO_4 > Ca > Na > K > Si$. Concentrations of the remaining sixteen constituents (Al, As, Be, Cd, Co, Cr, Cu, Fe, Mn, Mo, Ni, P, Pb, Sb, Se, Sn, V, and Zn) were below detection limits in all extracts.

The extract data were grouped by the seven sample types (i.e., the seven major stratigraphic units) used to generate the extracts. Trends were apparent when the average concentrations for the various constituents were compared for the different sample types (Table 2). The general trends noted in this evaluation were: (1) Maquoketa shale extracts had greater Ca, K, Na, SO_4, and TOC concentrations and lower pH values than the other extracts; (2) Galena Group, Wise Lake limestone extracts often contained the lowest constituent concentrations; and (3) dolomite extracts from samples of the Galena Group, Dunleith and Wise Lake Formations were similar in composition.

A one-way analysis of variance (ANOVA) was performed on the extract data to ascertain if the mean-constituent concentrations were significantly different among the seven sample types at a significance level of 5% ($\alpha = 0.05$). Chloride, Mg, Si, and TOC concentrations in all of the extracts were not significantly different from each other, while Ca, K, Na, and SO_4 concentrations, and pH and EC were different in extracts generated by the various sample types. Results of the statistical evaluation suggested that *in situ* leachates generated by the various spoil materials would be significantly different from each other.

ASTM extract data were compared to drinking water and surface discharge effluent standards to evaluate the potential environmental impact of disposal of the tunnel spoil on surface and groundwater supplies. The approach used in this comparison was to average the concentrations for all 39 extracts. The rationale behind this approach was that the various spoil materials would likely be mixed at the disposal site, and the process of averaging constituent concentrations in all the extracts would best approximate leachate concentrations under these conditions. Table 3 compares the average extract constituent concentration with drinking water and surface effluent discharge water quality standard concentrations. In all cases, where standards are available, extract constituent concentrations and pH values were within the standard ranges.

Total organic carbon (TOC) analysis was used to quantify but not identify the organic components in the ASTM extracts. The TOC results suggested a slight potential for the leachates generated by the tunnel spoil materials to contribute to the organic loading of surface or groundwater sources. The range of organic carbon concentrations in the extracts was from less than detection limits (0.05 mg/L) to 9.66 mg/L, with approximately 50% of the extracts containing concentrations less than 1

mg/L. The relatively low organic carbon contents of the extracts implied that any organic loading by leachates from the spoil on surface and subsurface waters would be minor.

Individual compound identification of the organic fraction of the extracts was not performed. Organic compounds considered hazardous and/or subject to regulation are generally derived from industrial processes (i.e., insecticides and herbicides). Because the spoil material would be excavated from deeply buried stratigraphic units, the potential of the spoil to be contaminated by industrial wastes or surface runoff is minimal and compound identification was deemed unnecessary. The potential impact of the organic component of the spoil leachate on receiving surface and groundwater sources was concluded to be minimal.

Toxicity Characteristic Leaching Procedure (TCLP)

The Resource Conservation and Recovery Act (RCRA) of 1976 was enacted as a first attempt at setting guidelines for hazardous waste disposal. Of particular significance were procedures and standards to ascertain if a waste would be considered hazardous. As mandated by RCRA, there are 6 categories of hazardous wastes: (1) ignitable, (2) reactive, (3) infectious, (4) corrosive, (5) radioactive, and (6) toxic. The spoil material would not be classified as hazardous according to the criteria of the first five categories. However, the criteria establishing the toxicity of a substance are complex and involve generation of an extract. The waste can be classified as toxic if an extract obtained by the TCLP has trace metal concentrations greater than the primary drinking water standards by a factor in excess of 100, and/or the extract produces gene mutation or DNA damage in bacteria or mammalian cells.

Seven core samples, representing typical rocks from each of the major stratigraphic units which would be excavated during SSC tunnel construction, were subjected to the TCLP to evaluate if the spoil material would be considered hazardous by the toxicity criteria. The constituent concentrations that were above analytical detection limits in the TCLP extracts are given in Table 4. Based on the constituent concentrations in the extracts, the wastes would not be classified as toxic. Facilities to evaluate whether the extract would produce gene mutation were not available at the Illinois State Geological Survey. However, based on constituent concentrations in the TCLP extracts, the spoil material would not be classified as hazardous.

Equilibrium-Solubility Modeling of the ASTM Laboratory Extracts

The application of chemical equilibrium models can lead to useful insights into the geochemistry of aqueous systems, such as leachates generated by landfilled tunnel spoil materials, particularly in resolving the origins and interactions of the constituents dissolved in solution.

As a step towards understanding the extracts, chemical analyses of seventeen of the ASTM extracts were treated by the thermodynamic model WATEQ2F (Truesdell and Jones, 1974; Plummer et al., 1976; and Ball et al., 1979). This computer program calculated the ionic strength of each solution from the input chemical data. Calculated ionic strengths were used to determine single-ion activity coefficients via a Davies-extended Debye-Huckel equation that was used to con-

vert solution concentrations to thermodynamic activities. These calculated activities were plotted on mineral stability diagrams.

The primary reason for subjecting the core samples to the short-term (48-hour) ASTM procedure was to assess water-soluble constituents in the tunnel spoil materials. A period of 48 hours may or may not be long enough for all dissolution-precipitation reactions to reach equilibrium. The lack of equilibrium conditions may, in some cases, preclude the assessment of solubility relationships. To assist in the analysis, three of the carbonate samples were extracted for 45 days to provide a limited basis for comparison (Table 5). Constituent concentrations in the 45-day extracts were higher, and pH values lower than in the 48-hour extracts.

The solution equilibria of the extracts appeared to be relatively simple. After 48 hours of contact, all of the extracts of the dominantly-carbonate samples (i.e., the dolomite and limestone facies of the Galena-Platteville and Maquoketa Groups, and the Silurian formations) were supersaturated with respect to dolomite (Fig. 2). Consequently while dolomite was present in the solid wastes, it appeared that it was not controlling the aqueous solubility of Ca^{2+}, Mg^{2+}, or the pH of the solutions. The extracts may not have reached equilibrium with respect to dolomite during the 48-hour extraction interval. The time required to establish dolomite equilibrium is unknown (Stumm and Morgan, 1981). Moreover, the conditions under which dolomite precipitates in nature are not well understood. After 45 days of contact, the three carbonate samples (SSC 2, 4, and 14) remained supersaturated with respect to dolomite.

After 48 hours of contact, all carbonate extracts were supersaturated with respect to aragonite and calcite (Fig. 2). However, after 45 days of contact, the three carbonate samples appeared to be approaching calcite equilibrium. If the three samples that were subjected to the longer equilibrium interval were fairly representative of the other spoil materials, then it would appear that the equilibrium concentrations of Ca^{2+} and CO_3^{2-} in field leachates will be eventually controlled by calcite solubility. The extracts of the Maquoketa shale appeared to be in equilibrium with aragonite after 48 hours of contact. Aragonite could have precipitated after the dissolution of carbonate phases in the solid samples.

All of the extracts were undersaturated with respect to gypsum and anhydrite (Fig. 3). The Maquoketa shale samples contained sufficient gypsum to be detected by X-ray diffractometry, but no gypsum was detected in any of the carbonate samples. The extracts of the shale had not reached equilibrium in 48 hours; gypsum was still slowly dissolving. Roy et al. (1984) found that some laboratory extracts of coal-solid wastes known to contain anhydrite required approximately 7 days for well-defined equilibria to develop. After 45 days of contact, the three carbonate extracts (SSC 2, 4, and 14) remained undersaturated with respect to both gypsum and anhydrite (Fig. 3). These results suggest that Ca concentrations and the pH of *in situ* leachates will be influenced by calcite solubility. Sulfate concentrations would increase somewhat until the leachate equilibrated with respect to gypsum if it was present in the waste materials.

As discussed earlier, carbonate-sample extracts were characterized by relatively high pH values (pH 9.2 to 10) while extracts of the Maquoketa shale were lower; pH 7.6 to 8.3. The pH of a system containing $CaCO_3$ and water in equilibrium with the atmosphere is 8.4 (Garrels and Christ, 1965). After 45 days of contact, pHs of the three carbonate-sample extracts had decreased. Two of the

extracts (SSC 4 and 14) had pH values approaching the equilibrium pH of $CaCO_3$ (pH 8.4). Thus, it was concluded that the pH of *in situ* leachates may be relatively high initially, but will gradually decrease as the leachate-spoil system equilibrates with $CaCO_3$ (and possibly Mg-carbonate) phases.

CONCLUSIONS

On the basis of this study the following conclusions were made:

1. Extracts generated by the ASTM procedure contained detectable amounts of Ca, Cl, K, Mg, Na, Si, and SO_4.
2. pH values of the extracts ranged from 7.60 to 10.10.
3. For all water based extracts, mean constituent concentrations were below drinking and surface effluent discharge standards, although some individual samples exceeded those standards.
4. Total organic carbon concentrations in the water extracts ranged from less than detection limits to 9.06 mg/L, suggesting the water soluble organic component in the spoil samples was minor.
5. Although identification of individual organic compounds in the extracts was not performed, it was assumed that since the spoil material would be exhumed from deeply buried stratigraphic units, exposure to potentially hazardous organic materials is minimal and hazardous organic compounds would not be found in either laboratory extracts or *in situ* leachates.
6. Solubility modeling of the ASTM extracts suggested that shale samples would equilibrate with calcite and thus, calcium and carbonate concentrations of *in situ* leachates would be controlled by calcite solubility.
7. Long-term extraction studies indicated that leachates from the carbonate spoils would equilibrate with $CaCO_3$. The pH of *in situ* leachates may be relatively alkaline, but will gradually decrease as the leachate spoil-system equilibrates with calcite.
8. Exposure of selected core samples to the U.S. EPA toxicity characteristic leaching procedure indicated that the spoil material would be considered nonhazardous under extraction procedure toxicity guidelines.
9. Results of laboratory extraction and modeling studies demonstrated that leachates generated by the spoil material would be relatively innocuous, and would have minimal impact on local surface and groundwater sources. Disposal of the spoil material into dolomite quarries and/or gravel pits appears to be an adequate disposal and or storage plan which will not significantly alter present groundwater quality.

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Table 1. Average concentrations (mg/L) and standard deviations of extract constituents from 39 samples.

Constituent	Average[a] Concentration	Standard deviation
B	0.14	0.25
Ba	0.02	0.09
Ca	26.4	44.0
Cl	19.7	14.3
K	9.57	14.3
Mg	42.2	18.6
Na	21.2	43.9
Si	1.61	0.79
SO_4	144	234
TOC	2.05	2.99
pH	8.75	—
EC (umhos/cm at 25°C)	448	358
Eh (mV)	270	27
Alkalinity[b]	106	25.7

[a]If concentration was less than detection limit, one-half the detection limit was used in calculation of the average.
[b]As mg/L $CaCO_3$

Table 2. Summary of extract constituent concentrations as related to sample type.

Constituents	Ranking of average constituent concentration in relation to sample type
Ca	MS > MD > PD > GDD > SD > GWL > GWD
Cl	SD > GDD > PD > MD > GWD > GWL > MS
K	MS > MD > SD > PD > GWD > GDD > GWL
Mg	MD > PD > MS > GWD > SD > GDD > GWL
Na	MS > GWL > MD > GDD > GWD > SD > PD
Si	PD > GWD > SD > GDD > MD > GWL > MS
SO_4	MS >> MD > PD >> GWD > GDD > SD > GWL
TOC	MS > SD > MD > GDD > GWL > PD > GWD
pH	GWD > GDD > GWL > SD > PD > MD > MS
EC	MS >> MD > PD > SD > GWD > GDD > GWL

SD — Silurian, Dolomite
MS — Maquoketa, Shale
MD — Maquoketa, Dolomite
GWD — Galena, Wise Lake, Dolomite
GWL — Galena, Wise Lake, Limestone
GDD — Galena, Dunleith, Dolomite
PD — Platteville, Dolomite

Table 3. Comparison of average extract constituent concentration with drinking water and effluent standards.

Constituents	Average Concentration in Extracts[a,b]	Drinking Water Standards[b]	Effluent Standards for Surface Discharge[b]
B	0.14	N/S	N/S
Ba	0.02	1.0	2.0
Ca	26.4	N/S	N/S
Cl	19.7	250	N/S
K	9.57	N/S	N/S
Mg	42.2	N/S	N/S
Na	21.2	N/S	N/S
Si	1.61	N/S	N/S
SO_4	144	250	N/S
pH	8.75	5.5-9.5	6.0-9.0

[a]If concentration was less than detection limit, one-half the detection limit was used in calculation of the average.
[b]Concentrations in mg/L.
N/S — No standard.

Table 4. Constituent concentrations (mg/L) in U.S. EPA TCLP extracts.

Formation Lithology	Galena Dolomite	Maquoketa Dolomite	Dunleith Dolomite	Dunleith Dolomite	Maquoketa Shale	Wise Lake Limestone	Silurian Dolomite	Platteville Dolomite
Al	0.17	<0.09	0.13	0.12	<0.09	<0.09	1.58	0.31
Ba	0.02	<0.001	0.01	0.02	0.24	0.01	0.22	0.06
Ca	957	962	940	969	394	2165	649	1029
Fe	13.0	6.99	4.23	2.06	0.13	<0.04	7.53	0.21
K	<1.82	<1.82	<1.82	<1.82	23.7	<1.82	22.1	3.82
Mg	527	550	547	568	206	13.2	317	605
Mn	1.68	2.18	1.16	1.08	1.78	0.55	2.33	0.69
Na	<2.38	<2.38	<2.38	<2.38	1365	<2.38	17.0	<2.38
Si	0.30	0.25	0.27	0.34	1.82	0.07	2.83	0.38
Alkalinity[a]	2740	2780	2760	2640	2520	3380	920	2620
EC[b]	4600	4700	4600	4700	5400	5580	3400	5400
pH	5.36	5.36	5.36	5.45	5.47	5.92	4.55	5.51

[a]Total alkalinity as mg/L $CaCO_3$.
[b]Electrical conductivity (μmhos/cm).

Table 5. Comparison of constituent concentrations (mg/L) in 48 hour and 45 day extracts.

	Galena Dolomite SSC2		Maquoketa Dolomite SSC4		Galena Limestone SSC14	
Constituents	48 hr	45 day	48 hr	45 day	48 hr	45 day
B	<0.03	0.06	<0.03	0.05	<0.03	<0.03
Ba	<0.002	<0.002	0.004	<0.002	<0.002	<0.002
Ca	4.07	6.95	32.2	56.9	8.50	20.1
K	7.19	16.5	4.27	9.6	<2.76	3.88
Mg	35.5	97.0	75.2	160	7.11	16.1
Na	9.66	12.1	9.44	14.1	7.71	12.9
Si	1.89	1.88	0.76	1.45	0.83	1.85
SO_4	43.0	133	249	427	6.21	16.1
Alkalinity[a]	125	226	81	190	30	72
EC[b]	299	700	665	1090	120	250
pH	9.79	9.00	9.21	8.52	9.71	8.50

[a]Total alkalinity as mg/L $CaCO_3$.
[b]Electrical conductivity (μmhos/cm).

SYSTEM	SERIES	Group Formation	Graphic Log	Description
			Quaternary deposits above	
SILURIAN	ALEXANDRIAN	Kankakee		Dolomite, fine grained
		Elwood Wilhelmi		Dolomite, fine grained, cherty
ORDOVICIAN	Cincinnatian	Maquoketa		Shale and interbedded dolomite
	CHAMPLAINIAN	Galena Wise Lake		Dolomite, fine to medium grained
		Dunleith Guttenberg		Dolomite, fine to medium grained, cherty
		Platteville		Dolomite, very fine grained
		Ancell Glenwood St. Peter		Sandstone, fine to medium grain, well sorted; dolomitic, poorly sorted at top
	Canadian	Prairie du Chien		Dolomite, cherty; little sandstone, siltstone, and shale
CAMBRIAN	CROIXAN	Eminence		Dolomite, fine to medium grained, sandy; contains oolitic chert
		Potosi		Dolomite, fine grained
		Franconia		Sandstone, fine grained, glauconitic
		Ironton–Galesville		Sandstone, dolomitic, fine to medium grained
		Eau Claire		Sandstone, siltstone, shale, and dolomite; glauconitic
		Mt. Simon		Sandstone, coarse grained, poorly sorted
PRECAMBRIAN				Granite, red

Fig. 1. Stratigraphic column of bedrock units in SSC study area (modified from Kempton et al. 1985).

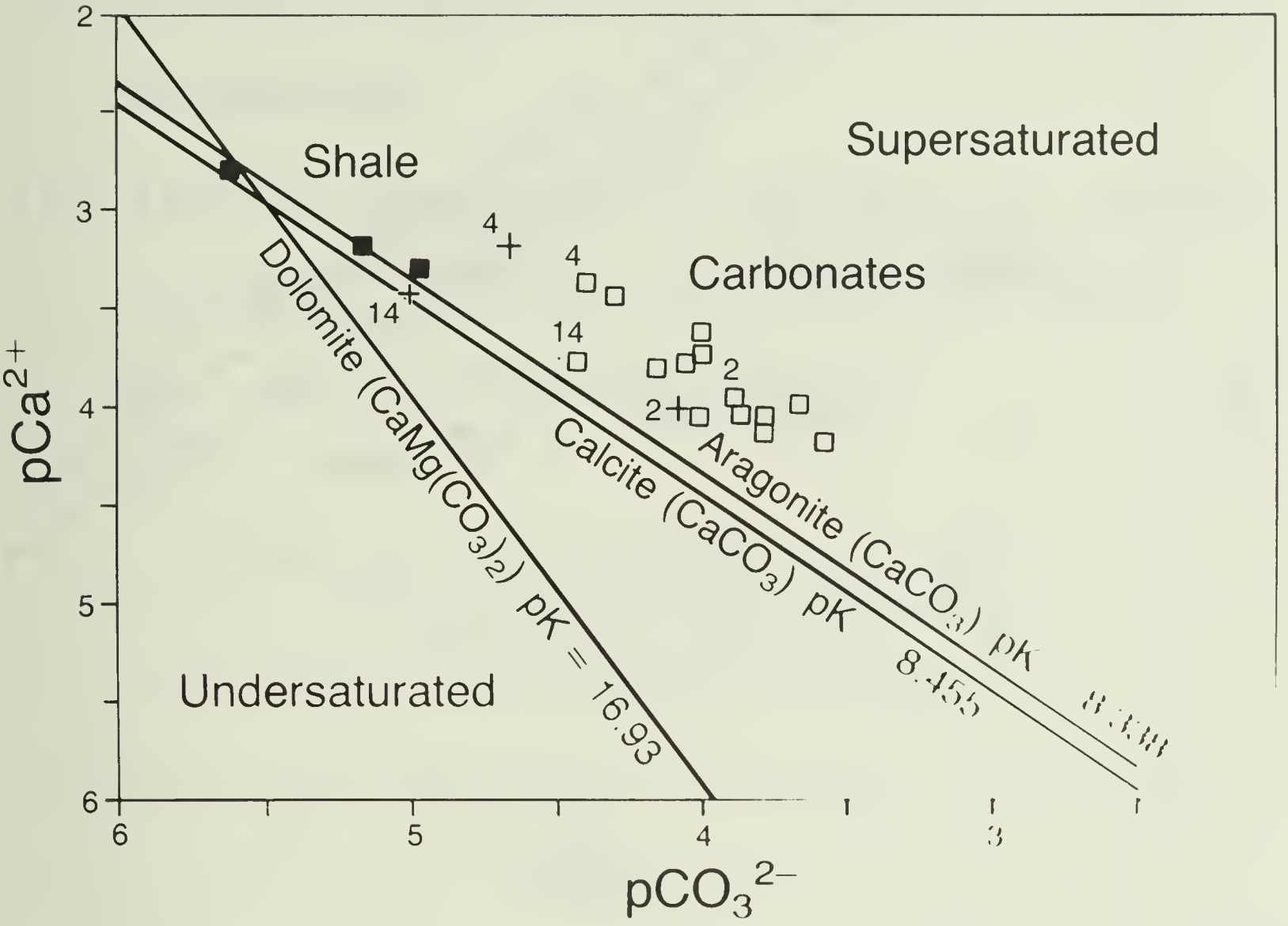

Fig. 2. Aragonite, calcite, and dolomite equilibria at 295°K, and 1 atmosphere pressure of the ASTM extracts of the core samples. The dolomite boundary was evaluated at pMg^{2+} = 3.0 M, the average Mg^{2+} content of the extracts. The squares represent the 48-hour extractions, with the solid and open squares representing the shale and carbonate samples, respectively. The crosses correlate to the long-term (45 day) extracts. The numbers (2, 4, and 14) refer to the Galena dolomite, Maquoketa dolomite, and Galena limestone samples, respectively.

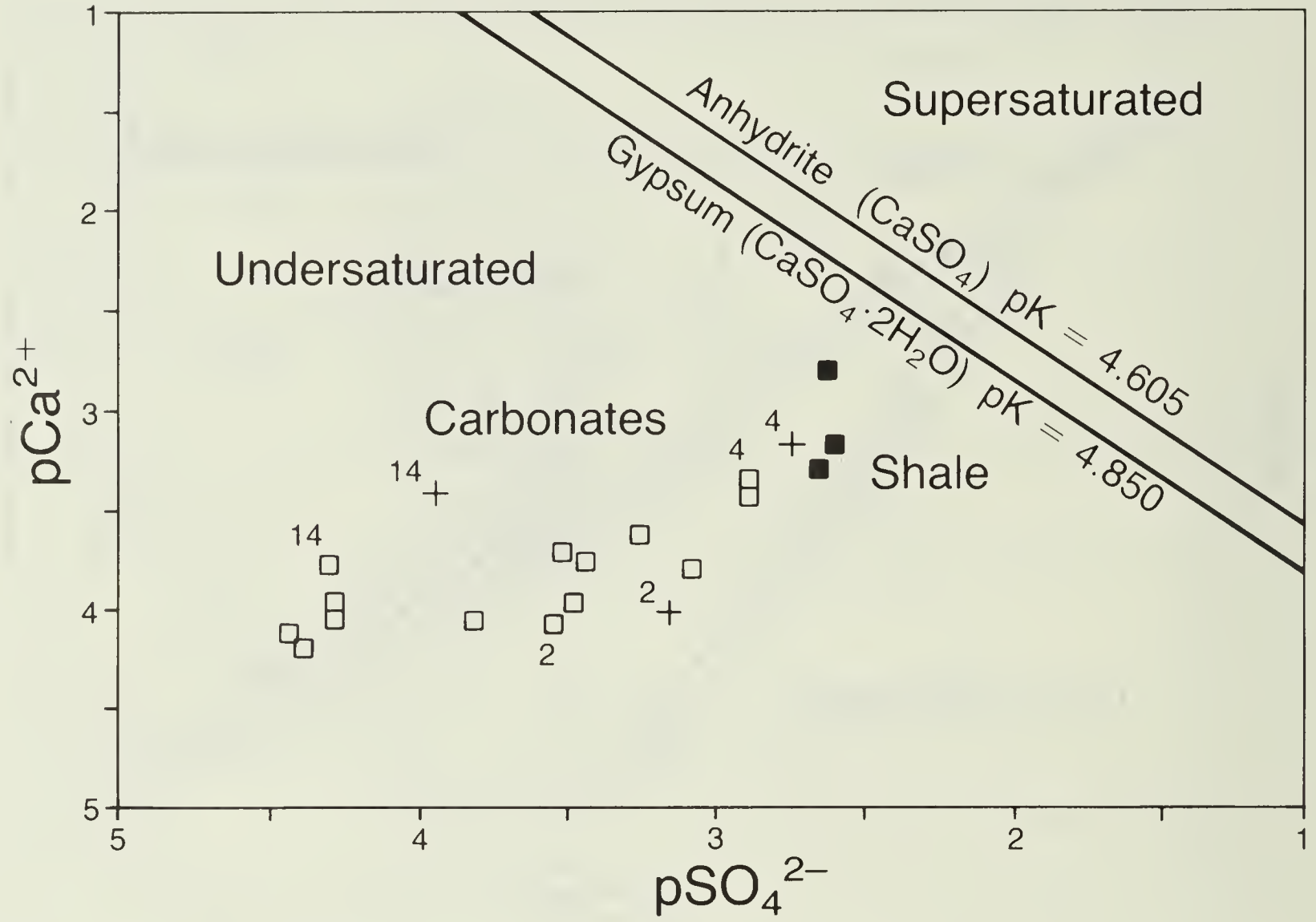

Fig. 3. Anhydrite and gypsum equilibria at 295° K, and at 1 atmosphere pressure of the ASTM extracts of the core samples. The squares represent the 48-hour extracts, with the solid and open squares representing the shale and carbonate samples, respectively. The crosses correlate to the long-term (45-day) extractions. The numbers (2, 4, and 14) refer to the Galena dolomite, Maquoketa dolomite, and Galena limestone samples, respectively.

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ILLINOIS BARREN LONGWALL MINE WASTE, FIFTY YEARS AFTER ABANDONMENT

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ABSTRACT

The establishment of vegetation in mined areas where conditions have not been restored is often very difficult because of generally steep topography, poor soil conditions, and low moisture levels. The Third Vein Subdistrict of the Longwall District in north-central Illinois is no exception. Although some areas have partially revegetated, many of the mine waste piles remain barren after more than 50 years of abandonment.

During May through August of 1982 and during June of 1983, an inventory and extensive sampling of plant species were performed on four sites of the Longwall Mine District. The mine spoil material was analyzed for over 20 characteristics.

Major factors contributing to unfavorable conditions for plant growth in this area included (1) inadequate soil moisture, (2) high soil (surface) temperatures, (3) high soil acidity (low pH), (4) nutrient deficiencies, (5) high salt levels, (6) instability and erodibility of the mine material, and (7) heavy metal toxicity. The purpose of this study was to assess the feasibility of revegetating the mine waste areas by examining (1) plant species currently existing on the sites and (2) potential soil modifications that might improve conditions for the establishment of vegetation.

INTRODUCTION

Illinois has an abundance of coal, with approximately 65% of the state overlying coal-bearing strata (Nawrot et al., 1982). Prior to the passage of the Federal Surface Mining Control and Reclamation Act of 1977, however, adequate reclamation was frequently not accomplished and a large number of sites have never been re-

claimed. One such area, the Longwall Mine District of north-central Illinois, contains over 100 refuse piles, the result of deep mining of Colchester (No. 2) coal between 1875 and 1930 (Bradford, 1983). The refuse material, locally called "gob," is unique because of the mining technique employed and because of the nature of the coal seam mined (Krapac and Smyth, 1982). The seam was about 1 m thick and a large amount of roof rock was also taken during the mining process. As a result, the refuse is composed of shales from the roof rock, along with coal scraps and clay cut out from under the coal. Since these refuse piles were flammable, they often burned, generally producing two types of material in addition to the unburned original gray refuse (Bradford, 1983). The partially heat-affected material is soft and reddish in color. The more completely burned refuse is hard (clinker) and brick-red in color.

The revegetation of most of the mine waste by natural processes, even after more than 50 years, is negligible. Most vegetative growth is confined to the lower slopes, especially the north-facing slopes (Nawrot et al., 1982; Iverson et al., 1983). Soil-water condition is often the most important factor in determining the success or failure of vegetation on mine spoils, but soil type, wind exposure, slope, surface material, surface temperature, nutrient status, and pH are also very important (Bramble and Ashley, 1955). Many edaphic factors affect plant establishment, particularly if water stress results (Croxton, 1928).

We report here on the vegetation of four mine waste sites that are similar in substrate and mining history but different in revegetation.

MATERIALS AND METHODS

The study sites are located in Illinois near the towns of Spring Valley, Standard, Ladd, and Wenona (Figure 1). Since the same coal seam has been mined across the entire region, the wastes were relatively homogenous. Compared to other mine wastes in Illinois, they are characterized by low potential acidity (Krapac and Smyth, 1982). Two of the sites (Spring Valley and Standard) are almost barren; two (Ladd and Wenona) have revegetated.

The mine at Spring Valley, which is located in Bureau County, opened in 1886 and closed in 1947. At one time this site had two mine piles. The larger was almost entirely removed years ago and the area it occupied has partially revegetated. The smaller remains and is essentially barren. Its steep slopes are severely eroded with extensive gullies. In an attempt to contain the mine waste, a ditch was dug to the south of the pile. More recently, removal of material from the eastern side of this pile has resulted in the loss of some adjacent vegetation.

The Standard site, located in Putnam County, had two large waste piles just outside a residential area. One was extensively burned, but both are extensively eroded and have affected neighboring farm fields and a nearby drainage ditch.

The Ladd site, in Bureau County, consists of two extensively burned mine waste piles that were barren and extensively eroded. One was planted with black locust (*Robinia pseudoacacia*) in the mid-1970s.

The Wenona site, in Marshall County, is confined on three sides by roads; a railroad borders the fourth. The top of the pile was removed by the Army Corps of Engineers in the 1950s, and the site was extensively modified for revegetation.

Black locust, honeysuckle (*Lonicera* sp.), and smooth brome (*Bromus inermis*) were planted.

Plant inventories at Ladd, Standard, and Spring Valley were conducted by dividing each pile into octants, thoroughly searching each octant, and recording all species encountered. The point-intercept method (States et al., 1978) was used to sample the extensively revegetated Wenona site. Woody vegetation was recorded along the transect; herbaceous vegetation was surveyed in rectangular plots (3 × 1 m) at predetermined intervals of 15 m. The inventories were carried out twice during May through August in 1982, and once during June of 1983. Specimens for all species encountered were pressed, dried, and deposited in the Illinois Natural History Survey herbarium. The nomenclature of Mohlenbrock (1975) and Hitchcock (1951) was followed.

The chemical and physical analysis of the mine wastes was conducted by dividing each of the four sites into quadrants. Eight samples were collected at a 10 cm depth from each quadrant between 2 to 3 m above the line of vegetation, a total of 32 samples per site. Soil water potential was determined from samples taken at a depth of 5 cm. The samples were ground to pass through 60-mesh.

Soil water potential was determined with a thermocouple psychrometer within 24 hours of sampling. Soil-moisture release curves were obtained by wetting the mine waste to saturation and allowing it to dry at room temperature. After a 24 hour equilibration period, percent moisture was determined by drying the waste at 100°C to constant weight.

Electrical conductance and pH measurements were made on waste material in suspension. Wastes were ground until they could pass through a 60-mesh screen and were then mixed 1:1 by weight with distilled water. Readings were taken after 24 hours (Sobek et al., 1978).

In order to determine the lime requirement of the mine wastes, the wastes were incubated with 0.04 N $Ca(OH)_2$ and a few drops of chloroform (Sobek et al., 1978). Lime requirements were then determined by adjusting the pH of the waste to pH 6.5.

Total nitrogen of the samples were determined by the Kjeldahl method (Bremner, 1965). Digestion was for 60 minutes with concentrated H_2SO_4, in the presence of the catalysts HgO and K_2SO_4. The ammonium ion produced by this oxidation was determined by making the solution strongly alkaline and distilling the ammonia into boric acid and back-titration with H_2SO_4.

Prior to cation analysis, samples were shaken on a rotary shaker for 1 hour and extracted with 0.05 N HCI and 0.05 N H_2SO_4 (Perkin-Elmer, 1976). Analysis was by direct-reading emission spectrophotometry with an inductively-coupled argon radio-frequency plasma torch source unit. Accuracy was determined by means of matrix-matched standards, which were run after every sixth sample. Limits of detection for the various elements were (mg/kg): Al 1.30, Be 0.05, B 0.10, Cd 0.18, Ca 0.18, Co 0.13, Cu 0.18, Fe 0.53, Mg 0.15, Mn 0.13, Ni, 0.38, P 2.05, K 2.90, Si 0.70, and Zn 0.28. Extraction of Hg was with HCI:HNO_3 (1:1, v/v) in the presence of $K_2S_2O_8$ and $KMnO_4$ (Jacobs and Keeney, 1974). Reduction of Hg to its vapor form, which was trapped as an amalgam on an activated silver wool plug, was with $SrCI_2$ (Long et al., 1973). The limit of detection was 5.0 ug/kg.

RESULTS AND DISCUSSION

Vegetation at the naturally revegetating sites was generally very sparse and was established primarily around the perimeters of the piles, on slumps, or in gullies. In total, 122 species were found on the four non-reclaimed study sites; richness at individual sites ranged from 39 to 71 species of vascular plants (Appendix). For comparison, Rastorfer and Wilhelm (1983) found 250 taxa of vascular plants on a reclaimed gob pile and surrounding areas in Macoupin County, Illinois. However, they included areas off the refuse area, such as abandoned pasture, woodlands, and pond margins. The relatively higher number of species found in the present study on the highly vegetated Wenona site was not unexpected, but the Standard site, which was nearly barren, had the next highest number (54). This site had been influenced greatly by the invasion of species from localities adjacent to the lower slopes of the pile. In general, vegetated areas had slopes that were less than 30° in steepness; steeper neighboring areas were generally barren. The steeper slopes tended to shed both water and seeds during periods of rapid runoff. These seeds settled on nearby flatter areas and germinated in less hostile environments.

Half of the average number of species found per octant at Spring Valley, Standard, and Ladd were "weedy" in nature; only 28 percent of the total species on the Wenona site were "weedy" (Table 1, Appendix). The major means of seed dispersion to the barren piles is generally via birds or wind (Ashby, 1964). The first invaders of mined areas or abandoned fields are primarily annual weeds (i.e., *Polygonum* sp., *Ambrosia artemisiifolia, A. trifida, Daucus carota,* and *Echinochloa crus-galli*) that are able to tolerate harsh conditions (McDougall, 1925; Quarterman, 1957; Leisman, 1957; Raynal and Bazzaz, 1973; Pickett and Bazzaz, 1978; Glenn-Lewin, 1979; Schafer and Nielsen, 1979; Iverson and Wali, 1982; Bares and Iverson, 1984).

The diversity of grasses were quite low at all sites, including the revegetated Wenona site (Table 1). Giant foxtail (*Setaria faberi*), a plant of open places, ditches, and waste ground, and Kentucky bluegrass (*Poa pratensis*), found in sparsely wooded areas, meadows, and open ground (Vogel, 1981), were among the more dominant grasses at the sites. Grasses made up roughly 20 percent of the species on the barren sites, but smaller proportions on the partially (Ladd) and completely vegetated (Wenona) sites (Table 1).

Herbaceous forbs consisted primarily of common ragweed (*Ambrosia artemisiifolia*), a native annual herb; white heath aster (*Aster pilosus*), often found in waste places and along railroads; and sour dock (*Rumex acetosella*), an introduced perennial often found on acidic soils (Wyman, 1971). Other common species included tall goldenrod (*Solidago canadensis*), dandelion (*Taraxacum officinale*), and horsetail milkweed (*Asclepias verticillata*) (Appendix). Forbs were the major component form on all sites (Table 1).

The dominant tree species, all native to Illinois, were box-elder (*Acer negundo*), a short-lived tree that grows well in poor, wet or dry soils and full sun; cottonwood (*Populus deltoides*) and large-toothed aspen (*Populus grandidentata*), often found in disturbed areas; black cherry (*Prunus serotina*), which volunteers frequently on mined sites; American elm (*Ulmus americana*), confined to more moist microenvironments, and slippery elm (*Ulmus rubra*), in moist to dry, slightly acidic areas.

Vegetation patterns by slope aspect for all sites except Wenona showed higher numbers of species for northern and eastern than for southern or western aspects (Table 2). Drier conditions due to higher solar irradiation and higher temperatures on southern and western slopes, conditions that were also found on North Dakota sites by Bares and Iverson (1984), probably contributed to the reduction in species numbers and cover. Species richness was five times greater on lower slope positions than on upper positions, a finding that relates to the availability of moisture as well as to the proximity of seed sources (Table 3).

The mine waste was generally of two types, a gray material and a red material. The gray material was the less altered, basically retained the original color, and consisted largely of shale, clay, and some pyritic material (Bradford, 1983). The red material resulted from oxidation of the gray waste, a process that also produced yellow to brown material. The gray waste was more acidic and saline than the red material (Table 4). Both types of waste had similar levels of Al, but the gray spoils, had higher levels of Fe and Mg. N and P levels were higher in the oxidized red waste.

Spoils at the barren sites had the lowest pH values, 3.3 at Spring Valley and 3.7 at Standard (Table 5). These acidities are usually toxic. The partially revegetated Ladd mine spoil had a pH of 3.8; the completely revegetated Wenona site had a pH of 5.0. Lime requirement and electrical conductance showed similar trends; spoils from the two barren sites had the highest lime requirement and conductance; the vegetated site at Wenona had the lowest (Table 5). The Al level at Spring Valley was twice (942 mg/kg that of the Wenona spoils (485). This level in combination with the high acidity at Spring Valley probably resulted in Al toxicity of sensitive plants (Byrnes et al., 1980). High Al levels also complicates susceptibility to water stress, since root growth in many soils will be restricted by the Al. Boron, Co, Fe, and Mg were in general also higher in spoils from the poorly vegetated mine sites; conversely Ca, Zn, K, and N were higher in the material from the revegetated site. Nitrogen was well below the minimum requirement for plant growth at the two barren and one partially vegetated sites (Hewitt and Smith, 1974). Phosphorus, another important plant nutrient, was low at all sites including the vegetated site at Wenona. Mercury, a very toxic heavy metal, was below 40 ppb at all sites.

Soil pH has a direct effect on the availability of nutrients. Acidity reduces the availability of P, Ca, Mg, K, and Mo, and increases the availability of Mn, Al, Fe and certain other heavy metals (Truog, 1951); the latter often leads to uptake by plants in toxic quantities (Jackson, 1967). Low soil pH also creates an unfavorable biotic environment.

The amount of moisture that is available to a plant depends on the relationship between soil water potential and plant water potential (Meidner and Sheriff, 1976). The percent of soil moisture is a direct measure of available water; however, it does not indicate the force required by the plant to remove that moisture from the soil. Soil water potential refers to this force, and Figure 2 shows the relationship between percent moisture content and its water potential for mine waste from the Standard site. To provide a point of reference, Figure 2 also shows the moisture-release curve for clay loam and sand. In general, the mine waste had a fair percentage of moisture but lost that water rapidly during drying, much as sand does; that is, the waste was quite "wet" after a rain but dried out rapidly.

Probably the most critical limiting factor for plants on the abandoned mine

spoils was the unavailability of water (Figure 3). The barren site at Spring Valley had the lowest available moisture. Even though more than 15 cm of rain were recorded during the first 15 days of July, at the end of July the water potential had dropped below 4 mPa on the southeast aspect. The vegetated site (Wenona) was able to conserve its moisture; and its potential did not drop to 1.5 MPa (often considered the permanent wilting point) until the middle of September, even after several weeks of below normal rainfall. Further, the availability of moisture on the poorly vegetated sites fluctuated greatly during the growing season compared to the Wenona site (Figure 3). During dry periods seed germination and establishment of plants is difficult but the vegetation itself influences the water status of the mine waste. The effect of vegetation on the conservation of moisture is quite evident at the Wenona site (Table 1, Figure 3). Precipitation that does not penetrate the soil is lost through runoff. The most important factors generally influencing runoff are steepness of slope, texture of material, and lack of vegetation. We estimate that runoff can exceed 80 percent of rainfall interception during certain storm events since slopes often exceed 30° and vegetation cover is minimal on most piles.

Another limiting factor for plant establishment could be salinity. Wenona had relatively low electrical conductivity readings; Spring Valley, on the other hand, had higher values which could inhibit plant growth (Table 5, E.C. values from 1:1 soil/water suspension). Other intensely salinized localities were observed on several piles in zones surrounding seepage areas. In these cases, E.C. values on a 1:1 suspension exceeded 12 mmhos/cm, and even tolerant plant species would be unlikely to survive under this kind of stress (Bradshaw and Chadwick, 1980).

CONCLUSIONS

Natural revegetation of mine waste piles in the Longwall Mining District has been slow. Based on the present investigation, the factor that most severely limits plants is the unavailability of moisture. The maximum moisture loss of the mine waste occurred at low soil water potential similar to sand. During the summer months the mine spoils showed great moisture deficiency. In addition, the slopes of the piles were very steep; many exceeded 35°. Rainfall did not readily penetrate the material and most of the moisture presumably was lost as runoff. In addition, the steep slopes facilitated erosion, which tended to undercut and bury establishing seedlings and to flush seeds downslope. The establishment of vegetation by natural means was, therefore, difficult.

A reduction in slope steepness would permit the penetration of rainfall and reduce erosion. Water harvesting and erosion-stabilizing structures would also be beneficial. Since the mine material had a poor structure, both water-holding capacity and cation exchange capacity could be improved through the addition of such soil amendments as sewage sludge or other mulching products. Greenhouse studies reported earlier (Iverson et al., 1983) showed substantial vegetation response to the addition of sewage sludge to mine waste.

Even though the pH of the mine waste was acidic, the lime requirement was quite low and the addition of lime might ameliorate acid conditions. Toxic materials, including heavy metals, did not present a major problem. Only elevated levels of Al and Zn were found; these elements can be tolerated by many plant species,

especially when the soil pH is nearly neutral. Salinity of the mine waste was at moderate levels and should in general not create special problems, with the exception of a few areas surrounding seeps. The mine waste was low in plant nutrients, and the application of fertilizers is required for adequate plant growth. The addition of organic matter would also improve the condition of the soil. To achieve minimum reclamation, the application of lime and fertilizer is necessary. The area must also be seeded with an appropriate species mix and mulched to conserve moisture during the critical period of plant establishment. A more extensive approach would include reduction of slope steepness, the installation of water-harvesting or water-supplying mechanisms, and the addition of organic material.

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Table 1. Vegetation characteristics of four abandoned mine sites. Mean of eight replicates (the eight cardinal directions of the pile), including both upper and lower positions of the slope.

	Average number of species per quadrant location				
	Spring Valley	Standard	Ladd	Wenona	P
Total species	4.6[a]	16.3[b]	13.1[b]	34.4[c]	≤0.001
Woody species	1.8[a]	5.0[a]	5.5[a]	13.1[b]	≤0.001
Forbs	1.9[a]	9.0[b]	6.5[b]	18.9[c]	≤0.001
Grasses	0.9[a]	2.3[bc]	1.1[bc]	2.4[c]	≤0.001
Weedy species	1.9[a]	8.0[bc]	5.8[b]	9.8[c]	≤0.001

Values followed by the same letters within a row do not differ significantly using Tukey's HSD test.

Table 2. Vegetation characteristics by aspect for Spring Valley, Standard, and Ladd sites. The Wenona site was excluded from this analysis because it was completely vegetated. Each number represents a mean of nine replicates.

	Average number of species per aspect								
	N	NE	E	SE	S	SW	W	NW	P
Total species	10.2[ab]	8.9[ab]	11.8[a]	8.3[ab]	7.9[ab]	5.6[ab]	5.9[ab]	4.8[b]	≤0.05
Woody species	3.8[ab]	3.3[ab]	5.3[a]	2.7[ab]	3.2[ab]	1.6[b]	1.3[b]	1.2[b]	≤0.01
Forbs	4.7[a]	4.6[a]	4.1[a]	3.7[a]	4.1[a]	2.4[a]	3.7[a]	2.6[a]	NS
Grasses	1.8[a]	1.0[a]	2.3[a]	2.0[a]	1.2[a]	1.6[a]	0.9[a]	1.0[a]	NS
Weedy species	4.3[a]	3.9[a]	4.9[a]	4.6[a]	4.1[a]	2.9[a]	3.0[a]	2.2[a]	≤0.05

Values followed by the same letters within a row do not vary significantly using Tukey's HSD test.

Table 3. Vegetation characteristics by position for Spring Valley, Standard, and Ladd sites. The Wenona site was excluded from this analysis because it was completely vegetated. Each number represents a mean of 24 replicates.

	Average number of species per position		
	Upper	Lower	P
Total species	2.1	10.6	≤0.001
Woody species	0.7	3.7	≤0.001
Forbs	0.8	4.6	≤0.001
Grasses	0.6	2.4	≤0.01
Weedy species	1.0	4.9	≤0.001

Values within each row differ significantly using Tukey's HSD test.

Table 4. Chemical characteristics of red and gray mine waste.

	Red (n = 15)	Gray (n = 17)	P
pH	4.44	3.50	≤0.05
E.C., mmhos/cm	0.30	2.04	≤0.01
Al, mg/kg	626.0	725.0	NS
Be, mg/kg	0.08	0.09	NS
B, mg/kg	0.52	0.60	NS
Cd, mg/kg	0.28	0.14	≤0.001
Ca, mg/kg	1125.0	1129.0	NS
Co, mg/kg	0.29	0.87	≤0.001
Cu, mg/kg	0.53	1.15	≤0.001
Fe, mg/kg	25.7	104.1	≤0.05
Hg, ug/kg	29.1	38.8	NS
Mg, mg/kg	180.3	460.1	≤0.001
Mn, mg/kg	22.4	33.4	NS
N, mg/kg	1448.0	890.0	≤0.05
Ni, mg/kg	1.06	2.66	≤0.001
P, mg/kg	4.86	2.51	NS
K, mg/kg	1361.0	361.0	≤0.001
Si, mg/kg	103.4	41.1	≤0.001
Zn, mg/kg	9.9	6.7	NS

Table 5. Chemical characteristics of spoils from the four mine sites. Each number represents a mean of eight replicates, except for lime requirement, which is based on four replicates.

	Spring Valley	Standard	Ladd	Wenona	P
pH	3.33[a]	3.70[a]	3.80[a]	4.95[b]	≤0.001
Lime requirement (tons/1,000 tons)	8.65	7.13	7.58	4.68	NS
E.C., mmhos/cm	2.40[a]	1.53[ab]	0.85[bc]	0.13[c]	≤0.001
Al, mg/kg	942.0[a]	531.0[b]	756.0[ab]	485.0[b]	≤0.001
Be, mg/kg	0.07	0.06	0.10	0.11	NS
B, mg/kg	0.67	0.69[a]	0.63[a]	0.24[b]	≤0.01
Cd, mg/kg	0.14[a]	0.12[a]	0.15[a]	0.40[b]	≤0.001
Ca, mg/kg	1013.0	1202.0	787.0	1507.0	NS
Co, mg/kg	1.24[a]	0.49[b]	0.33[b]	0.34[b]	≤0.001
Cu, mg/kg	1.28[a]	0.67[b]	1.17[a]	0.32[c]	≤0.001
Fe, mg/kg	73.9[ab]	132.6[a]	56.9[ab]	5.9[b]	NS
Hg, ug/kg	33.5	37.8	29.7	36.2	NS
Mg, mg/kg	574.0[a]	326.0[b]	151.0[b]	264.0[b]	≤0.001
Mn, mg/kg	41.6[a]	23.5[ab]	14.3[b]	33.6[ab]	≤0.05
N, mg/kg	905.0[a]	597.0[a]	952.0[a]	2360.0[b]	≤0.001
Ni, mg/kg	3.4[a]	1.7[b]	1.0[b]	1.5[b]	≤0.001
P, mg/kg	0.8	4.0	7.4	2.2	NS
K, mg/kg	418.0[a]	446.0[a]	874.0[a]	1581.0[b]	≤0.001
Si, mg/kg	43.7[a]	57.3[ab]	73.2[b]	106.9[c]	≤0.001
Zn, mg/kg	4.8[a]	3.5[a]	3.7[a]	20.9[b]	≤0.001

Values followed by the same letters within a row do not vary significantly using Tukey's HSD test.

APPENDIX
Species List of Vascular Plants for the Study Sites

Species	Spring Valley	Standard	Ladd	Wenona
Acer negundo L.	+	+	+	+
A. saccharinum L.	+	+	+	+
Achillea millefolium L.		+		
Agropyron repens (L.) Beauv.	+	+		
Agrostis alba L.		+		
A. hyemalis (Walt.) B.S.A.		+		
Ailanthus altissima (Mill.) Swingle			+	+
Ambrosia artemisiifolia L.	+	+	+	+
A. trifida L.				+
Antennaria plantaginifolia (L.) Richards		+		
Arctium minus (Hill) Bernh.		+		+
Asclepias syriaca L.	+	+	+	+
A. verticillata L.	+	+	+	+
Aster pilosus Willd.	+	+	+	+
Atriplex sp.	+			
Atriplex patula L.		+		+
Bidens frondosa L.			+	
B. vulgata Greene				+
Botrychium dissectum Spreng.		+		
Bromus commutatus Schrad.				+
B. inermis Leyss.				+
Catalpa bignonioides Walt.				+
Celtis occidentalis L.				+
Chenopodium album L.				+
Cichorium intybus L.	+	+		
Cirsium discolor (Muhl.) Spreng.				+
C. vulgare (Savi) Tenore				+
Commelina communis L.				+
Convolvulus arvensis L.		+	+	+
Dactylis glomerata L.				+
Danthonia spicata (L.) Beaur.	+			
Daucus carota L.	+	+		
Digitaria Sanguinalis (L.) Scop.	+			
Echinochloa pungens (Poir.) Rydb.	+		+	
Elymus canadensis L.	+	+		
Erechtites hieracifolia (L.) Raf.			+	+
Eupatorium altissimum L.	+		+	+
E. rugosum Houtt.			+	+
Euphorbia spp.				+
Euphorbia helioscopia L.				+
Fragaria virginiana Duch.	+			+
Fraxinus americana L.	+			+

F. pennsylvanica var. *subintegerrima* (Vahl) Fern.			+	+
Geum laciniatum Murr.				+
Hackelia virginiana (L.) I. M. Johnston				+
Helianthus annuus L.		+		
Hordeum jubatum L.	+	+		
Ipomoea batatas (L.) Lam.	+			
Juncus tenuis Willd.		+		
Juniperus virginiana L.		+		
Lactuca spp.		+		
L. floridana (L.) Gaertn.				+
L. serriola L.	+			+
Lonicera spp.		+		+
Maclura pomifera (Raf.) Schneider				+
Malus pumila Mill.		+		
Medicago lupulina L.		+		
Melilotus alba Desr.		+		+
M. officinalis (L.) Lam.	+	+		
Mentha arvensis L.				+
Mirabilis nyctaginea (Michx.) MacM.				+
Morus rubra L.		+	+	+
Nepeta cataria L.			+	+
Oenothera biennis L.				+
Oxalis stricta L.				+
Panicum capillare L.				+
P. dichotomiflorum Michx.			+	+
P. virgatum L.	+			
Parietaria pennsylvanica Muhl.				+
Parthenocissus quinquefolia (L.) Planch.		+		+
Phleum pratense L.		+		
Physalis subglabrata Mack. & Bush			+	
Phytolacca americana L.				+
Plantago lanceolata L.	+			
Poa pratensis L.	+	+	+	+
Polygonum sp.				+
Polygonum aviculare L.	+			+
P. lapathifolium L.			+	
P. pensylvanicum L.				+
P. pensylvanicum var. *laevigatum* Fern.	+	+		
Populus deltoides Marsh.		+	+	
P. grandidentata Michx.		+	+	
Potentilla sp.			+	
Prenanthes alba L.	+			
Prunus serotina Ehrh.	+	+	+	+
Pyrus communis L.		+		
Quercus macrocarpa Michx.	+			
Q. velutina Lam.	+			
Ribes cynosbati L.				+

R. missouriense Nutt.		+		
Robinia pseudoacacia L.			+	+
Rosa carolina L.		+		
R. multiflora Thunb.		+	+	+
Rubus spp.		+	+	+
Rumex acetosella L.	+	+	+	
R. altissimus Wood		+		
R. crispus L.			+	
Setaria faberi Herrm.	+	+	+	+
Silene cucubalus Wibel			+	+
Solanum americanum Mill.	+		+	+
S. dulcamara L.				+
Solidago canadensis L.	+	+	+	+
S. graminifolia (L.) Salisb.		+		
S. juncea Ait.	+			
S. nemoralis Ait.	+	+		
S. rigida L.				+
S. speciosa Nutt.	+			
Sonchus asper (L.) Hill				+
Symphoricarpos orbiculatus Moench.		+		
Taraxacum officinale Wiggers	+		+	+
Toxicodendron radicans (L.) Kunze	+	+		
Tragopogon dubius Scop.			+	
Trifolium pratense L.		+		+
Ulmus americana L.	+	+	+	
U. pumila L.		+		+
U. rubra Muhl.	+		+	+
Verbena bracteata Lag. & Rodr.	+			
V. urticifolia L.			+	+
Viburnum opulus L.				+
Viola spp.				+
Vitis riparia Michx.		+	+	+
Xanthium strumarium var. *canadensis* (Mill.) Torr. & Gray		+		
Totals (122 species on all sites)	42	54	39	71

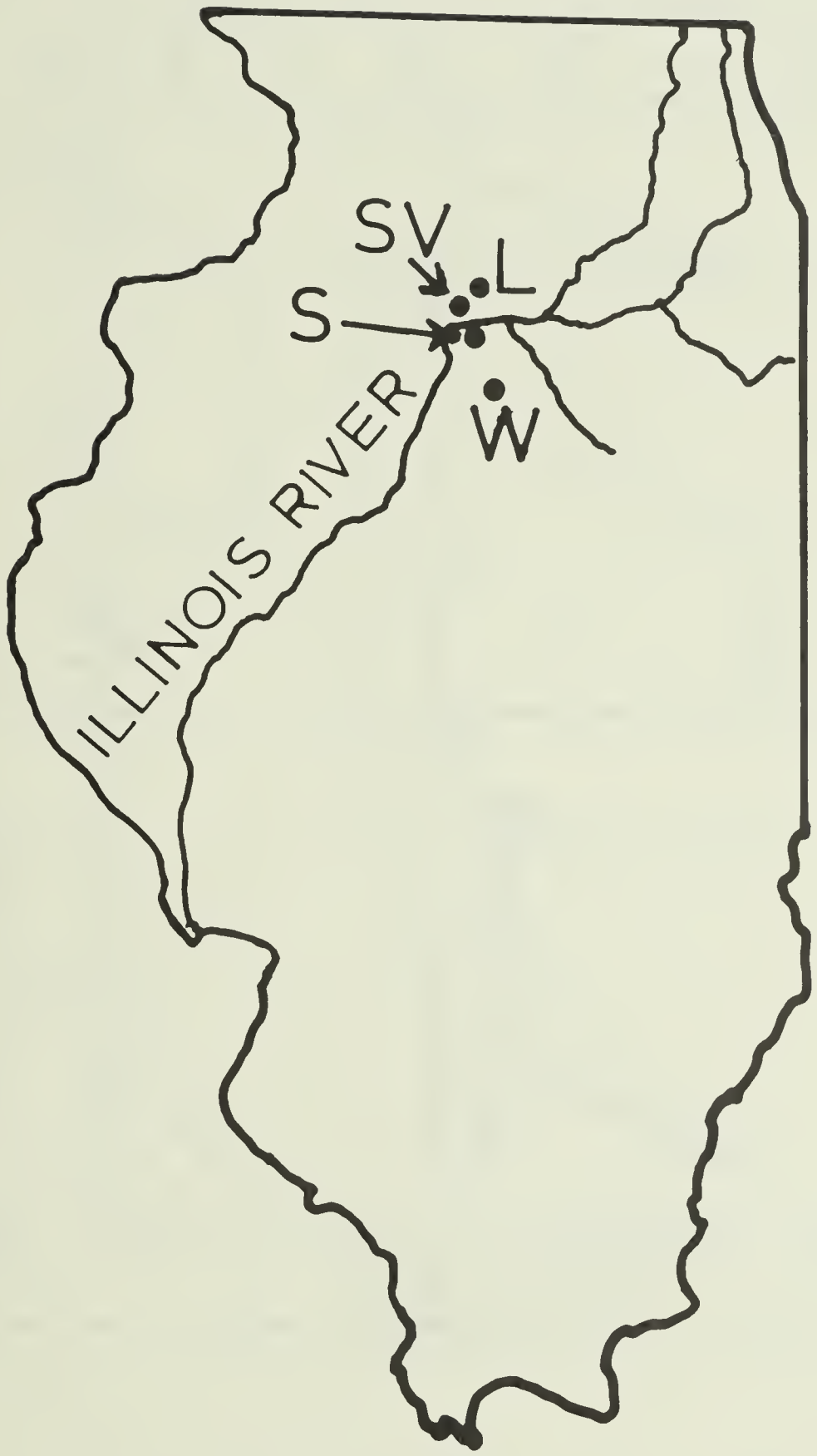

Fig. 1. Location of Illinois study sites: Spring Valley (SV), Standard (S), Ladd (L), and Wenona (W).

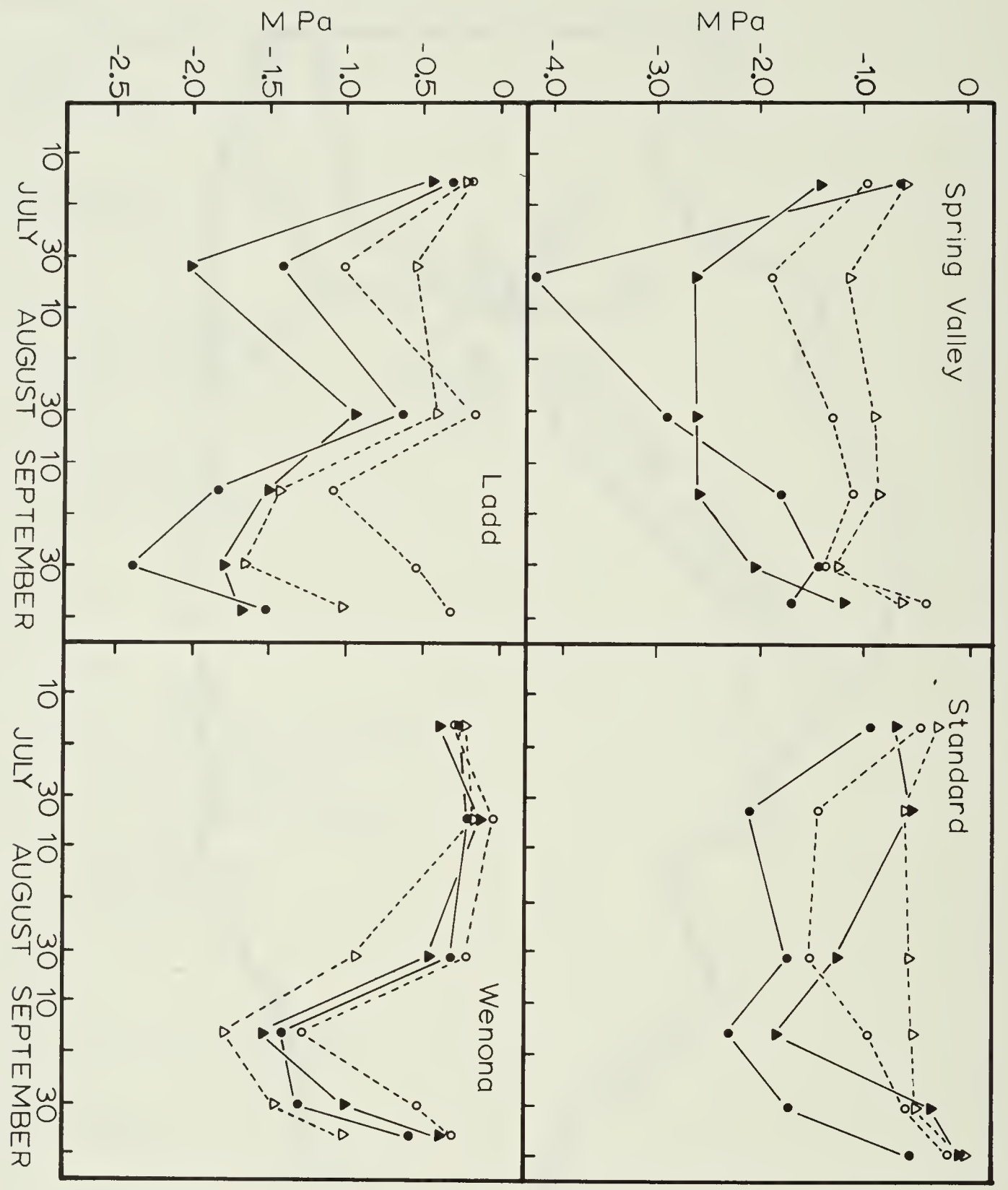

Fig. 2. Moisture release curve of mine waste from the Standard site. For comparison, curves of typical sand and clay loam are also given.

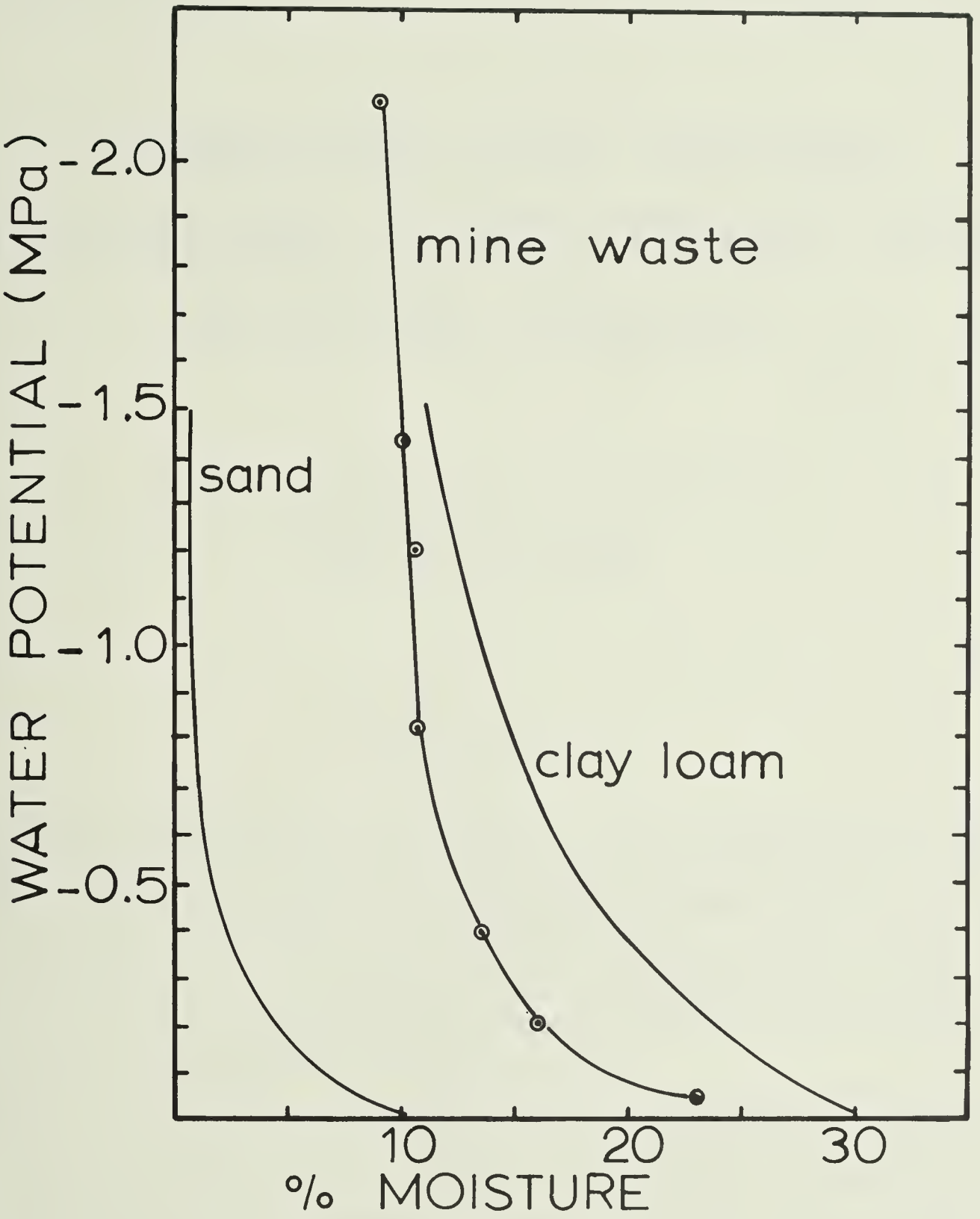

Fig. 3. Soil water potential of the four mine sites from 16 July through 5 October 1982. Slope aspect southwest (▲), southeast (●), northwest (△), and northeast (○).

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A TORNADO AND SEVERE WINDSTORM CLIMATOLOGY FOR ILLINOIS: 1955-1986

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ABSTRACT

The Illinois tornado and severe windstorm record from 1955 to 1986 is presented and compared with earlier data. Illinois experiences about 28 tornadoes per year on the average, although the actual annual frequencies vary from as few as 7 (1964) to as many as 107 (1974). Total tornado frequency is shown by county, as well as weighted by area. In addition, an index is presented wherein equal area tornado frequencies are adjusted by a rural and total population function, thus minimizing biases introduced by population density.

Whereas several earlier studies have shown mean monthly Illinois tornado frequency to maximize in April, these data show maximum frequency in June, closely followed by April and May, with the tornado "season" essentially delimited by March and September, though tornadoes have occurred in all months of the year in Illinois. In the mean, tornadoes are most frequent in the (1) northeastern, (2) west central, (3) central, and (4) southern sections of the state.

1. Introduction

Although the average annual wind speed in Illinois varies from about 8 to 12 mph, strong, damaging winds occur during all months of the year. Spring storms are either caused by intense cyclones (storm centers), or by thunderstorms and tornadoes. Those during late spring and summer are most likely associated with convection in the form of thunderstorms or tornadoes, whereas those during the colder months of the year are associated with intense cyclones and cold fronts. Thunderstorms exhibit stornger winds and are of shorter duration than the winds

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due to cyclones. They may exceed 60 mph (tornadoes exceeding 200 mph) and may continue for a few tens of minutes. Winter winds are generally less than about 100 mph, but may persist for several hours or more than one day.

The down-rushing air from thunderstorms moves out in all directions from under the thunderstorm cloud as the air nears the earth's surface, often reaching speeds of 60 mph or more. This outflow may extend for several tens of miles outside the outer edge of the thunderstorm cloud. It is impossible to specify the extreme speed of these winds because anemometers are only located at about 25 sites in Illinois. Since severe thunderstorms and tornadoes are less than a few miles in diameter, the wind speeds of most of these phenomena are never observed with the existing network of meteorological sites.

2. Quality of Tornado Data

Observations of tornadoes and the archiving of these observations has improved since the turn of the century. As recent as the early 1950s however, records of tornado occurrences were incomplete because no concerted effort was being made to archive that information on a continuing basis. Although the U.S. Weather Bureau (now the National Weather Service) began to actively gather (as opposed to only *receive*) tornado observations in the mid-1950s, even observations from the most recent years are somewhat suspect.

First, not all tornado observations are necessarily reported to the National Weather Service. Second, if the tornado, itself, is not seen, but only the damage is investigated, the possibility exists that the damage due to a tornado may be categorized as that due to straight line winds, or vice versa. Even professionals disagree as to the cause of any specific damage pattern. Therefore, individual tornado data must be suspect. The quality of tornado data since 1973 was further questioned by Changnon (1982). Prior to that year, U.S. Weather Bureau and/or Environmental Scientific Services Administration State Climatologists visited tornado sites and verified occurrence and damage. After 1973, when the federal State Climatologist program was terminated, site verification was much reduced, and the numbers of tornadoes may be overstated due to the observer attributing damage to tornadoes as opposed to strong straight-line winds. When average frequencies are constructed however, we believe that erroneous data are largely filtered from the results. The material of this paper are composed of such averages.

3. Intensity of tornadic winds

Limited observation, experience and research suggest that although tornadoes generally move forward at relatively slow speeds of 10 to 50 mph, the wind speeds *around* the tornado may exceed 250 mph. Illinois tornadoes have been categorized by intensity since 1970. Eighty-seven percent of the 530 observed tornadoes in Illinois during that time exhibited wind speeds less than about 160 mph.

Though not the state with the highest tornado frequency, nor located in the heart of "tornado alley," Illinois experiences about 28 tornadoes each year (1955-1986 average). The loss of life with any one event is a function of the size and movement of the tornado, the effectiveness of the communications alert system, and is strongly dependent upon the trajectory of the tornado, i.e., whether it moves through a major population center. Illinois is located on the northern periphery of

"tornado alley" (roughly Texas, north-northeastward to Illinois), a favored location for tornado occurrence in the United States, and, indeed, in the world.

4. Early Tornado Reports in Illinois

Tornado statistics for Illinois from 1916 through 1969 were presented by Changnon (1971) and are not repeated here. Instead, this discussion will focus on 1955-1986 data, the most recent 32 years. Pre-1916 tornado occurrences in Illinois are summarized below, recognizing that the list is incomplete. The record is incomplete because not all tornado occurrences were seen nor were they recorded, and written records from the 19th century may have been lost. For example, only 27 tornadoes were recorded in Illinois from the early 1800s through 1870 according to Ludlum (1970) and the U.S. Weather Bureau (listed in Table 1). The 1805 event represents the first surviving record of a tornado in Illinois. The event reported for April 1852 may have included several tornadoes. Four lives were reported lost in the Pana tornado of June 1857, 19 at Ellison (May 1858), and 26 in the Camanche tornado (June 1860). During the 30 years from 1870 to 1899, 81 tornado reports in Illinois survive. The tornado of 21 April 1912 must have been phenomenal in strength, and the magnitude of damage suggests that it occurred over a heavily populated area.

5. The Illinois Tornado Record since 1955

Total number of tornadoes, tornado days, deaths, and injuries from 1955 to 1986 are shown in Table 2. The data of Table 2 are comparable to those presented by Changnon (1971: Table 2) using tornado data from 1916 to 1969. Although Changnon summarized 54 years of data, and the data of this study encompass 32 years, the mean number of tornadoes per year in Illinois increased from 10 to 28 from his study to this one, and the number of days per year with tornadoes increased from 5 to 12. While each of these tornado frequencies increased by a factor of 2 to 3, the average annual number of tornado-caused deaths decreased from 19 to 5 per year (factor of about 4). The average number of tornado-related injuries remained essentially constant, i.e., 110 and 95 per year. The increase in number of tornadoes is probably the result of a better, more complete data gathering program, rather than an actual change in tornado frequency. The substantial decrease in deaths is undoubtedly related to a better understanding of tornadoes by the general public, and to a much better communication system whereby advisories and warnings are quickly disseminated to inhabitants of the potential area of impact. Incidently, if the 1,061 injuries of 1967 are neglected, the average number of injuries per year in Illinois would only be 64, as opposed to 95.

Of all the years with data, 1973 and 1974 clearly stand out as the years with more tornadoes reported in Illinois than in any other year. However, deaths and injuries were below the 32 year average.

Using 1916-1969 data, Changnon (1971) showed that most Illinois tornadoes occurred during April followed by May, March and June, in decreasing order. These 4 months included 66% of the annual tornadoes. The data from 1955 through 1986 indicate that June exhibits the most frequent tornadoes, followed by April, May and August (see Fig. 1). Indeed, these 4 months include 72% of the total annual number of tornadoes in Illinois. The reason for this difference is unknown. It may

be related to the observed cooling trend in Illinois since about 1930, but this suggestion has not been rigorously tested.

Illinois ranks eighth of all states in the total number of tornadoes since 1955, it ranks ninth in the number of tornado-days, and tenth in the total number of tornado-related deaths for the same period. If data since 1916 had been included, Illinois would rank first of all states in the number of tornado-related deaths because of the Tri-State Tornado, a phenomenal event of 18 March 1925 which moved from Missouri through Illinois into Indiana (described by Changnon & Semonin, 1966), and accounted for 606 deaths, making it the single worst tornado event in terms of loss of life in United States tornado history.

Fig. 2 shows the total tornadoes observed within each of the 102 counties of Illinois from 1955 to 1986. The distribution of tornadoes in the state changed somewhat from that of 1916 to 1969 data (Changnon, 1971). Recent data show maximum frequencies in the northeast, the east-central and central sections of Illinois, and also within a small area east of St. Louis (Fig. 2). To compensate for small and large area counties, the raw county frequencies were adjusted for the area of each county, and are reported as tornadoes per 100 square miles in 32 years of record in Fig. 3. Note that although the absolute values change, the overall pattern and locations of maximum and minimum frequencies remain much the same.

Areas with maximum tornado activity in Fig. 3 suspiciously congregates around the major population centers of the state, suggesting that perhaps reports of tornadoes are at least in part, influenced by population density, i.e., more people in an area (up to a point) enhance the possibility that a tornado will be seen and recorded, or conversely, few observers may be spread so thin that tornadoes occur, but are not seen.

To test the impact of varying population densities, a tornado index was constructed after that suggested by Agee (1970). The index is calculated as follows.

$$\text{Tornado Index (county)} = \frac{\dfrac{\textit{tornadoes}}{\text{rural population (county)}}}{\dfrac{\textit{tornadoes}}{\text{rural population (state)}}}$$

This index "corrects" raw data for urban population densities (assuming that the high population densities of urban areas will amplify frequencies), and presents each county value relative to that for the entire state, i.e., an index of 1.0 is equivalent to the state average, 2.0 is twice that of the state, etc. The distribution of indices (Fig. 4) show values greater than 1.0 from west-central counties toward the northeast, east and southeast, and a second area in southern counties. These findings differ only slightly from those compiled from 1916 to 1969 data presented by Changnon (1971), where he showed the greatest indices from roughly the St. Louis area toward the northeast. The similarity in the 2 patterns is largely the result of 15 years of common data (1955-1969) in the 2 studies. Although the pattern of high index counties is essentially the same in the 2 studies, Changnon identified a total of 48 counties with indices greater than 1.0, whereas we only identified 31 such counties. Twenty of our high index counties are common with those of Changnon, and 11 of ours were identified as low index counties in Changnon's study. There is no systematic change from his pattern (his Fig. 7) to that in ours. The reason(s) for

these observed differences are unknown. They may only reflect differences in potentially discontinuous data sets, such as are tornado observations.

Tornado intensities have been defined according to wind speed and damage by Fujita (1981) and are summarized in Table 3. The frequency of various intensity storms in Illinois since 1970 are presented in Table 4. For each of the years with more than about 30 tornadoes, the distribution of the various intensity storms is heavily skewed toward the lower intensities, i.e., tornadoes with maximum winds of 112 mph or less, comprising about 2/3 of the total.

6. Severe straight line winds not associated with tornadoes

Strong straight line (non-rotating) winds can occur during any season of the year in Illinois, though they are most frequently observed during the warmer months. Indeed, 86% of all reported straight-line windstorms from 1960 through 1986 occurred from March through August. Their mean monthly distribution is shown in Fig. 1. Note the interesting, but inexplicable month-to-month increases from January through July. The climatology of straight line windstorms in Illinois was reviewed by Changnon (1980) and will not be duplicated here. In the present paper, we look only at the distribution of straight line windstorms from data extracted from *Storm Data*, published by the National Weather Service.

Straight line winds are caused by strong cyclones (low pressure cells or storm centers) or near strong fronts primarily in winter, or by non-tornadic thunderstorms primarily in spring and summer. The resulting winds from either source are essentially the same, i.e., non-rotating, but with speeds greater than about 40 mph, but generally less than 100 mph. The strong winds associated with moving storm centers may persist for hours or an entire day. Those associated with thunderstorms generally persist for 30 minutes or less. Damage, however, may be great, since the damage is largely a function of the strength of the wind, rather than its duration.

The distribution of straight line windstorms by county from 1960 to 1986 is shown in Fig. 5, and per 100 square miles per county in Fig. 6. Note that both patterns generally conform to those of tornado distributions found in Figs. 2 and 3.

7. Change in tornado and straight line winds from 1955 to 1986

The number of straight-line windstorm days and tornado days per year for 1960 to 1986 (extracted from *Storm Data* from 1960 to 1986) are shown in Fig. 7. Annual windstorm days occurred more frequently than tornado days except during the 9 years from 1962 to 1970. Although the correlation coefficient between these 2 variables is only +0.56, a similarity is noted in the trends of each of the 2 curves. There are three episodes: (1) relatively low frequencies until about 1971 or 1972, (2) rising to a relatively high frequency for 3 to 6 years until 1975 or 1977, and (3) falling again to the present value.

8. Summary and Conclusions

Illinois' relatively flat, low-relief topography enhances the possibility of strong winds. Such winds occur because of intense cyclones, cold fronts, and coldwaves in winter, and thunderstorms and tornadoes in spring and summer, and to a lesser extent, in fall. Destructive winds can occur during all months of the year. Those in winter tend to range from 40 to 60 mph, and continue for several hours or even from

one day into the next; whereas thunderstorm-related winds during the warmer months tend to be stronger (perhaps greater than 100 mph), but usually exhibit a tenure measured in only a few tens of minutes.

Although tornado observations are more complete today than they were in the 19th century, records of individual storms from the last decade are still suspect due to population spatial density differences, and mis-identification of tornadoes and straight line winds. We believe that errors in the record tend to be random and therefore averaged data are meaningful.

The mean annual frequencies of tornadoes and straight line winds in Illinois are similar, *i.e.*, about 10 each per year from 1960 to the early 1970s; followed by about 35 tornadoes (15 straight line windstorms) per year to about 1976; and about 25 tornadoes (10 straight line windstorms) per year thereafter. We do not know whether these discontinuous episodes reflect actual frequency changes, or, rather, reflect changes in observation verification, or recording procedures.

Both strong straight-line and tornadic winds are most frequently observed in west central, north central and northeastern, and in southern Illinois. During the last 32 years of record, June has recorded the greatest monthly tornado frequency, followed by April, May and August; those months include 72% of the annual mean. Straight line winds occur with increasing frequency from January through July. There has been no change in the annual tornado frequency since the mid 1950s. Changes prior to that time were likely due to incomplete records.

Using tornado data since 1955 (1960 for straight line winds), Illinois experiences about 28 tornadoes, 12 days with tornadoes, and 24 days with straight line windstorms annually. Monthly tornado frequencies increase from about 1 per month from October to February, to about 5 per month in April, May and June. Straight line windstorms, on the other hand, increase rather linearly from fewer than 1 per month in October to February, to more than 5 per month in July, with a general decline to October.

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Table 1. Date and location of tornadoes in Illinois during the nineteenth century through 1870 (from Ludlum, 1970), and from 1900 to 1915 (from Weather Bureau records, 1900-15). County of occurrence given in parentheses.

Date	Location
5 June 1805	St. Louis and east into St. Clair County
27 May 1850	Nauvoo (Hancock)
30 April 1852	Golconda (Pope) into Indiana
13 June 1857	Pana (Christian)
31 May 1858	Ellison (Warren)
26 May 1859	Calhoun-Greene-Scott-Morgan Counties
2-3 June 1860	Camanche IA to Whiteside County to the east-northeast to Elgin area (Cook)
9 November 1864	Chester (Randolph) and Hoyleton (Washington)
12 April 1903	Logan, Dewitt and Piatt Counties
17 April 1903	Henry and Walnut (Bureau and Marshall)
18 April 1903	Cambridge (Henry)
11 April 1905	Hillsboro (Montgomery)
28 April 1905	Crawford County
10 June 1905	Galva (Henry)
19 June 1905	Rushville (Schuyler)
27 March 1908	Knoxville (Knox), Monmouth (Warren) and Pontiac (Livingston)
11 May 1908	Mercer County
28 May 1908	Pike County
25 November 1908	southeast St. Clair County, 125 ft. wide path
11 July 1909	Vermilion County
15 April 1910	Madison, Macoupin and Montgomery Counties, ½ mile wide path. "Enormous" hailstorm at Hillsboro
22 May 1910	Cairo (Pulaski), 6 houses moved off foundations
12 September 1910	Iroquois County
11 November 1911	Tornado characteristics noted prior to a severe coldwave in Illinois
21 April 1912	LaSalle and Livingston Counties, path was 100 to 1,300 ft. wide. 18 dead in Illinois. Damage estimated $1 million in 1912 dollars. Another tornado reported in Murphysboro where 9 people were killed, 75 injured, 22 houses lost and 106 houses damaged.
26 April 1912	Carbondale (Williamson) and east. 1 person killed. Path width from 400 to 500 ft.
3 May 1914	Galva (Henry) and Peoria (Peoria). 2 dead.

Table 2. Tornado and windstorm statistics for Illinois for the years 1955 through 1986.

Year	Tornadoes	Tornado Days	Deaths	Injuries	Windstorm Days
1955	23	10	0	9	*
1956	27	18	8	31	*
1957	42	12	15	319	*
1958	27	13	2	17	*
1959	36	20	1	5	*
1960	36	18	0	31	32
1961	35	16	2	142	33
1962	10	9	0	2	9
1963	13	8	2	114	10
1964	7	4	0	3	14
1965	27	12	8	211	12
1966	11	8	1	50	11
1967	40	14	59	1061	12
1968	8	3	8	135	10
1969	10	8	0	4	17
1970	17	12	0	2	8
1971	16	13	1	48	9
1972	30	14	5	81	32
1973	63	25	0	11	27
1974	107	25	2	67	50
1975	46	28	2	78	45
1976	27	13	4	118	30
1977	33	7	6	61	45
1978	13	7	1	4	20
1979	12	11	0	1	21
1980	14	9	0	7	33
1981	33	14	1	48	20
1982	35	17	13	287	31
1983	14	5	2	43	28
1984	34	13	1	20	27
1985	15	12	1	20	25
1986	21	9	0	12	35
Total	882	396	150	3,042	646
Mean, per year	27.6	12.4	4.7	95.1	23.9
Std. Dev.	19.5	5.9	10.6	193.7	12.1

*data not available.

Table 3. Tornado intensities, after Fujita (1981).

Intensity	Characteristic
F –	Little or no damage, 40 mph or less
F 0	Light damage to branches, signboards, 40 to 72 mph
F 1	Moderate damage, roofs, mobile homes and moving automobiles particularly susceptible, 73 to 112 mph
F 2	Considerable damage, boxcars overturned, large trees uprooted, 113 to 157 mph
F 3	Severe damage, walls of structures blown down, most trees in forest blown down, cars lifted off road and blown, 158 to 206 mph
F 4	Devastating damage, houses leveled, buildings blown off foundations, 207 to 260 mph
F 5	Incredible damage, large houses lifted off foundation and blown substantial distances or demolished, automobile-sized missiles fly through air, 261 to 318 mph
F 6	Inconceivable damage, 319 mph or greater

Table 4. The frequency of Illinois tornadoes according to the "F" intensity scale of Fujita (1981).

Year	F0	F1	F2	F3	F4	F5	F6	Unk	Total
1970		8	5					4	17
1971	2	12	1	1					16
1972	5	15	7	2	1				30
1973	22	27	13	1					63
1974	57	15	18	9				8	107
1975	15	12	15	4					46
1976	4	2	13	5	3				27
1977	7	13	2	2	1			8	33
1978	1	5	5	1				1	13
1979	1	4	1	1				5	12
1980	8	1	5						14
1981	14	14	2	1	2				33
1982	24	3	3	3	1			1	35
1983	4	5	3	2					14
1984	19	12	2	1					34
1985	6	6	3						15
1986	9	9	3						21
Total	198	163	101	33	8			27	530
Percent of Total	37	31	19	6	2			5	

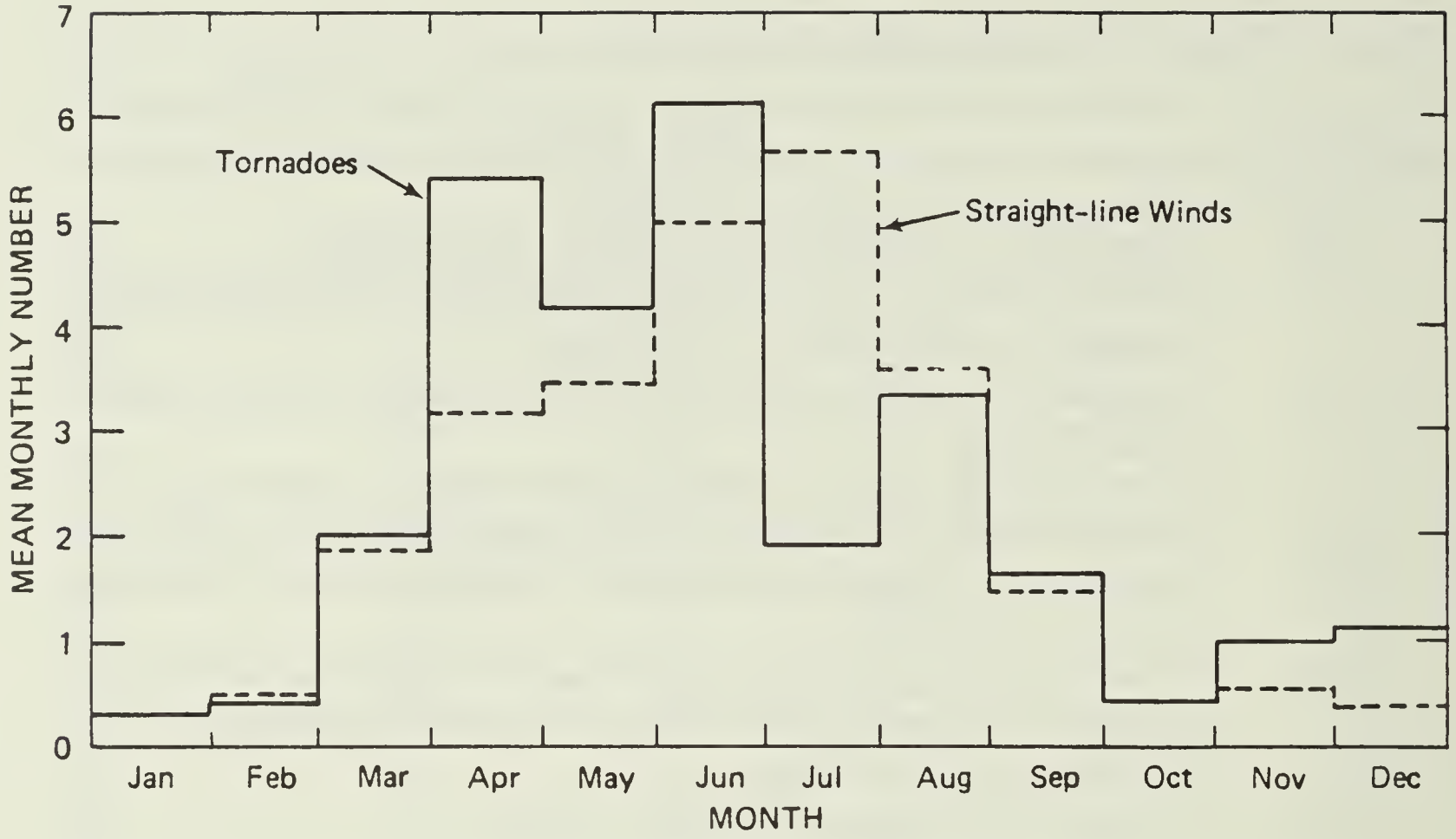

Fig. 1. Mean number of days per month with tornadoes, and straight line windstorms (1955-1986 data).

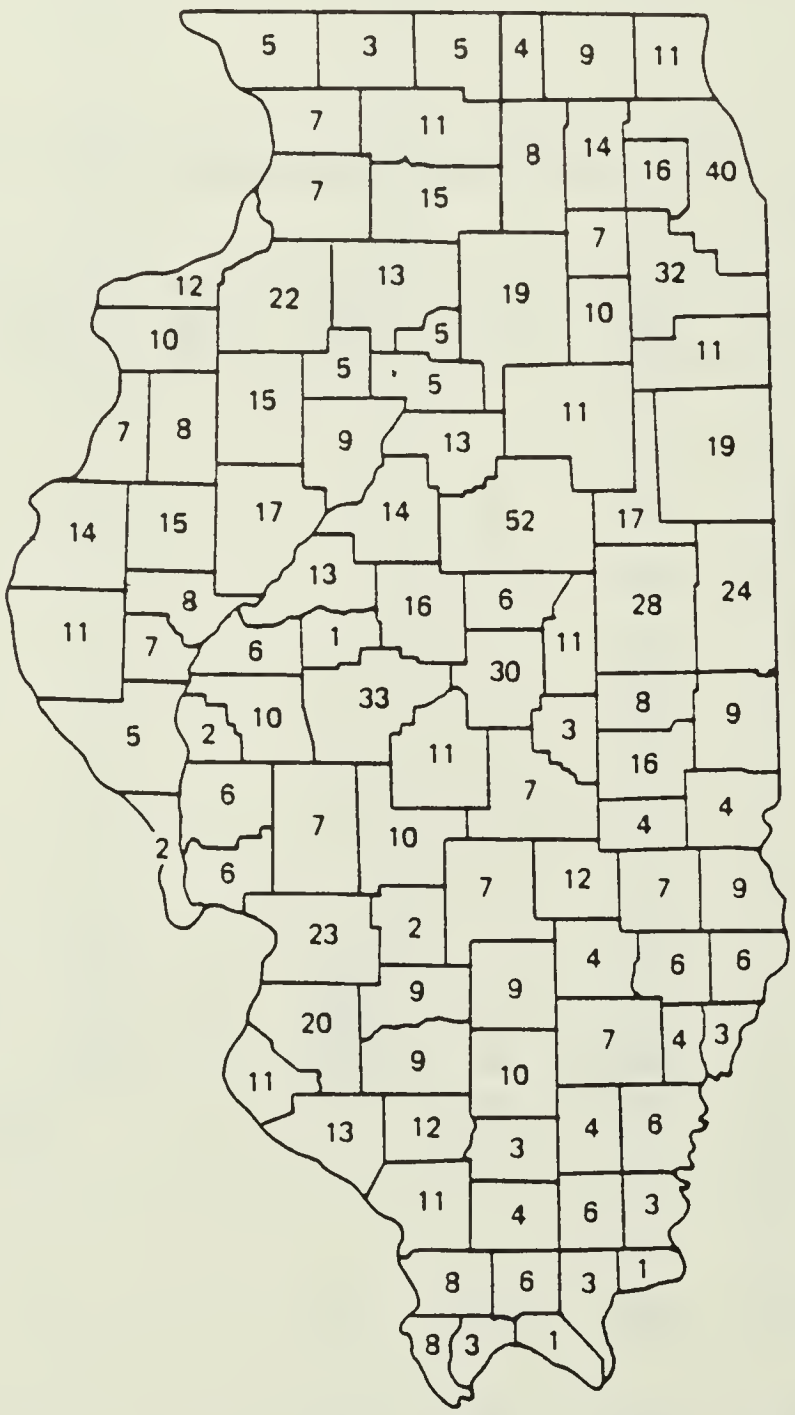

Fig. 2. Total tornadoes reported by county from 1955 through 1986.

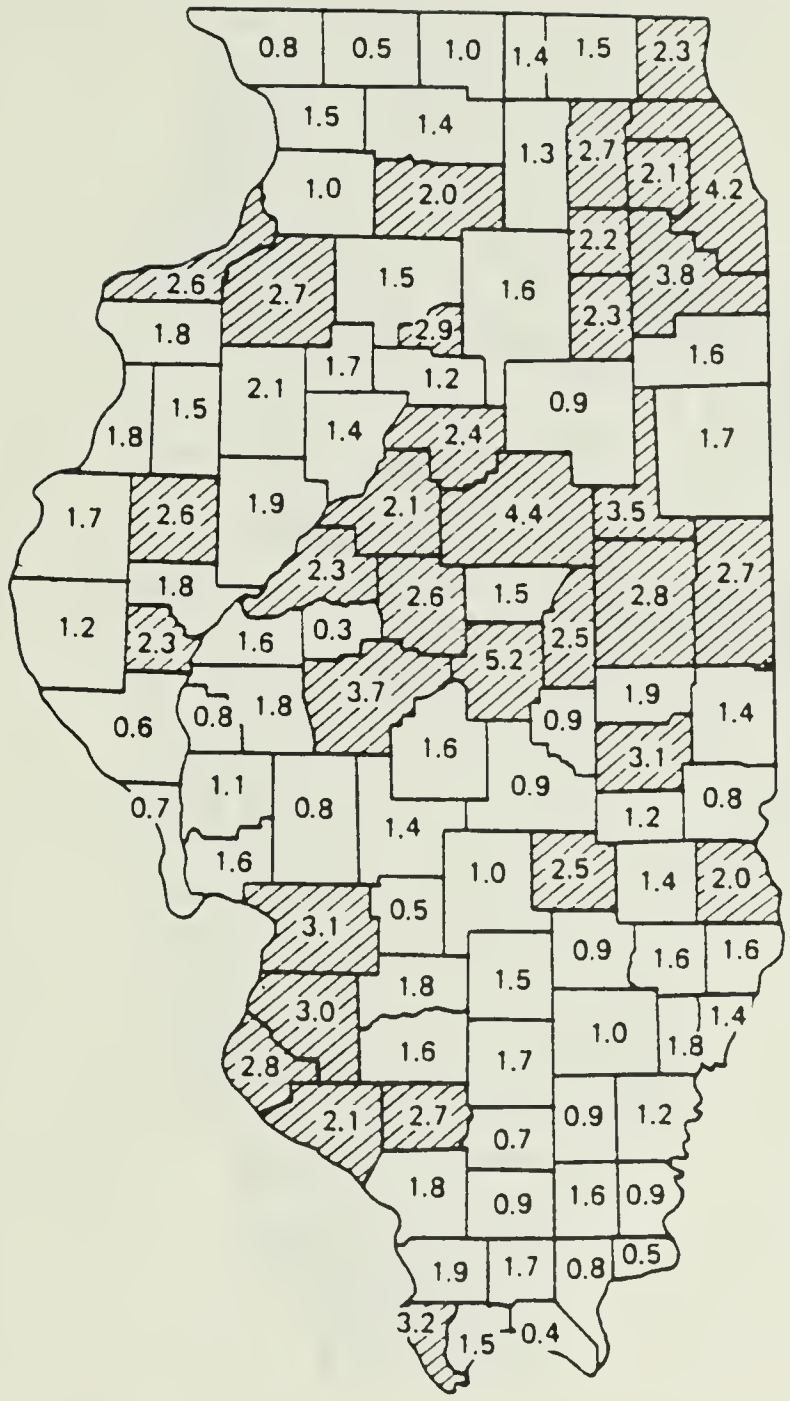

Fig. 3. Total tornadoes reported by county from 1955 through 1986, expressed as total tornadoes per 100 square miles. Totals of 2.0 or greater are shaded.

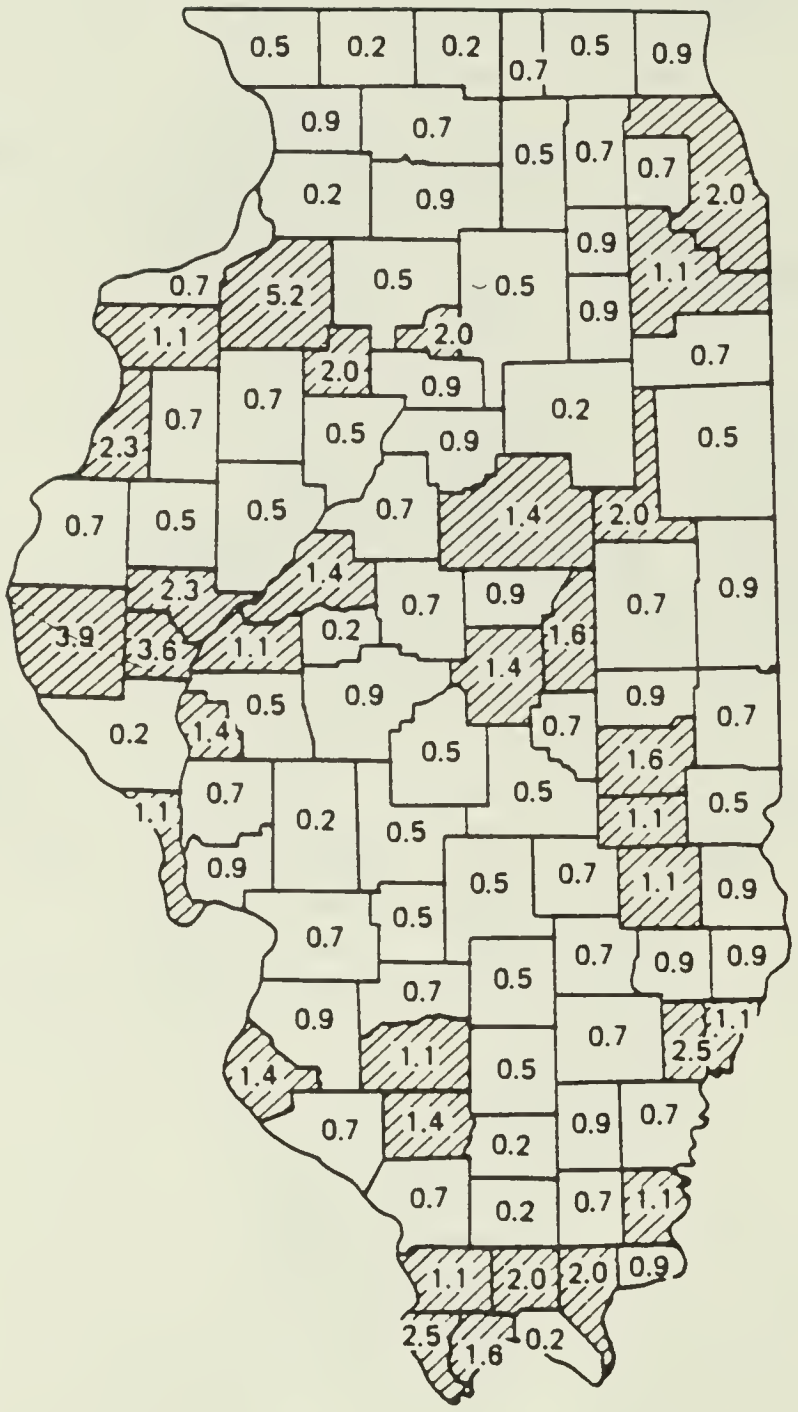

Fig. 4. Tornado index by county (1.0 = statewide mean; see text for explanation) (1955-1986 data). Totals of 1.0 or greater are shaded.

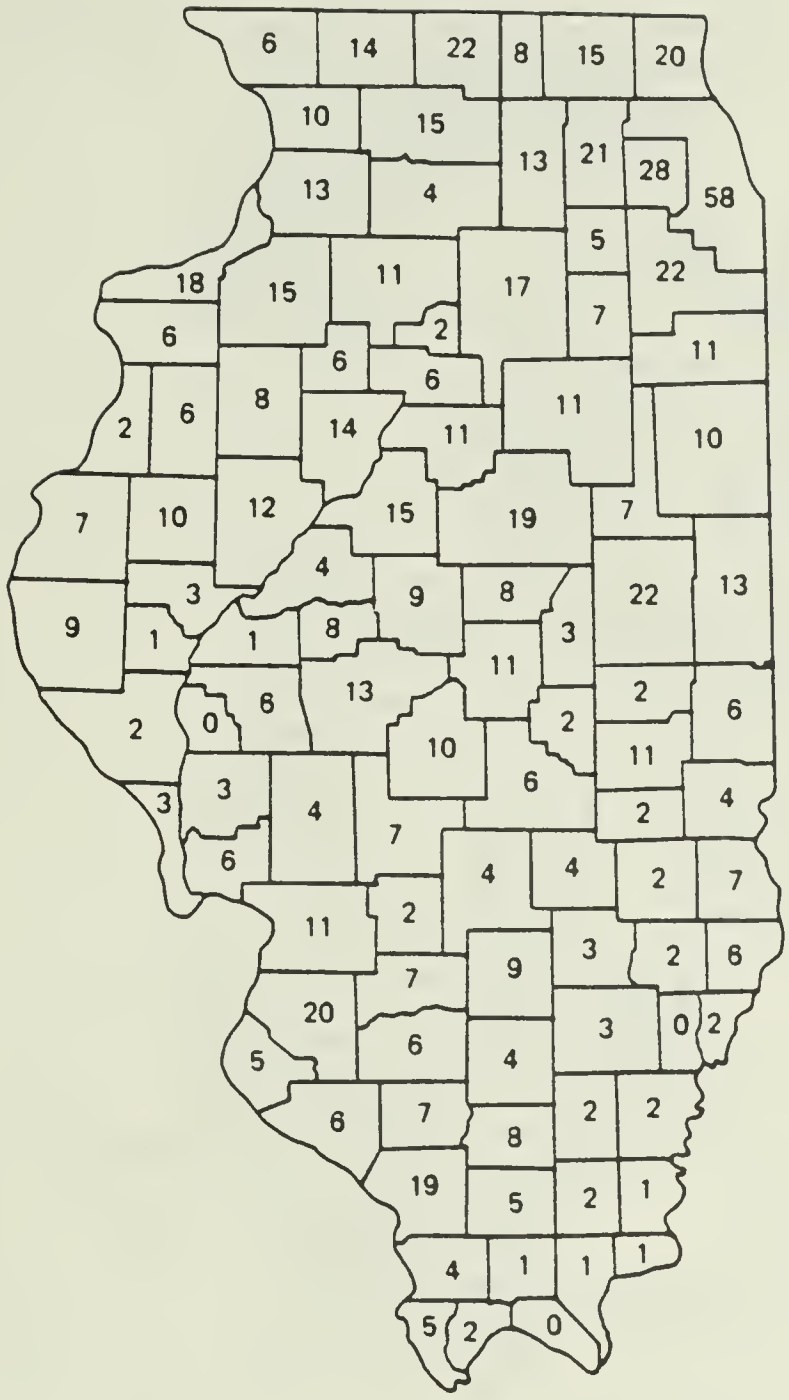

Fig. 5. Total straight-line windstorms by county, reported from 1960 through 1986.

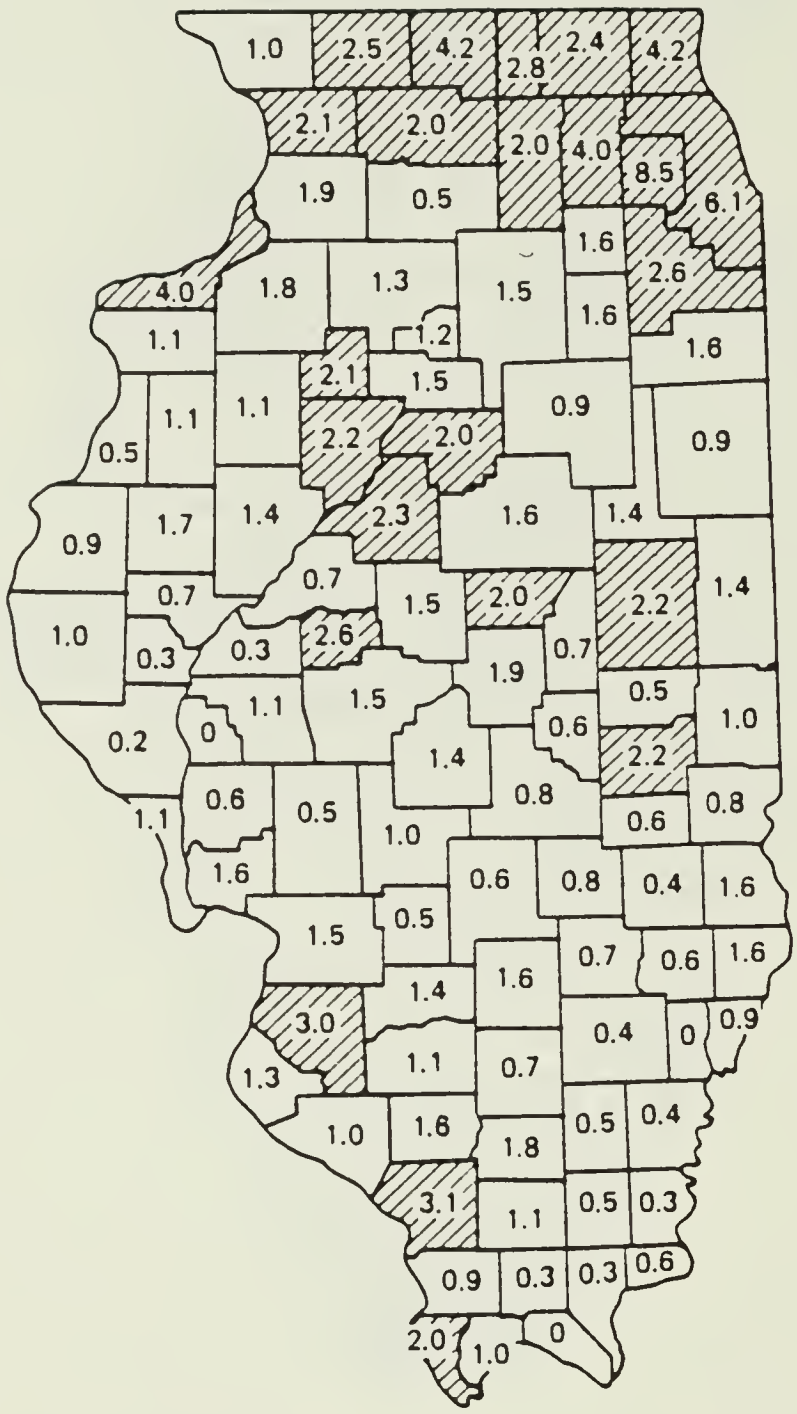

Fig. 6. Total number of straight-line windstorms by county, per 100 square miles, reported from 1960 through 1986.

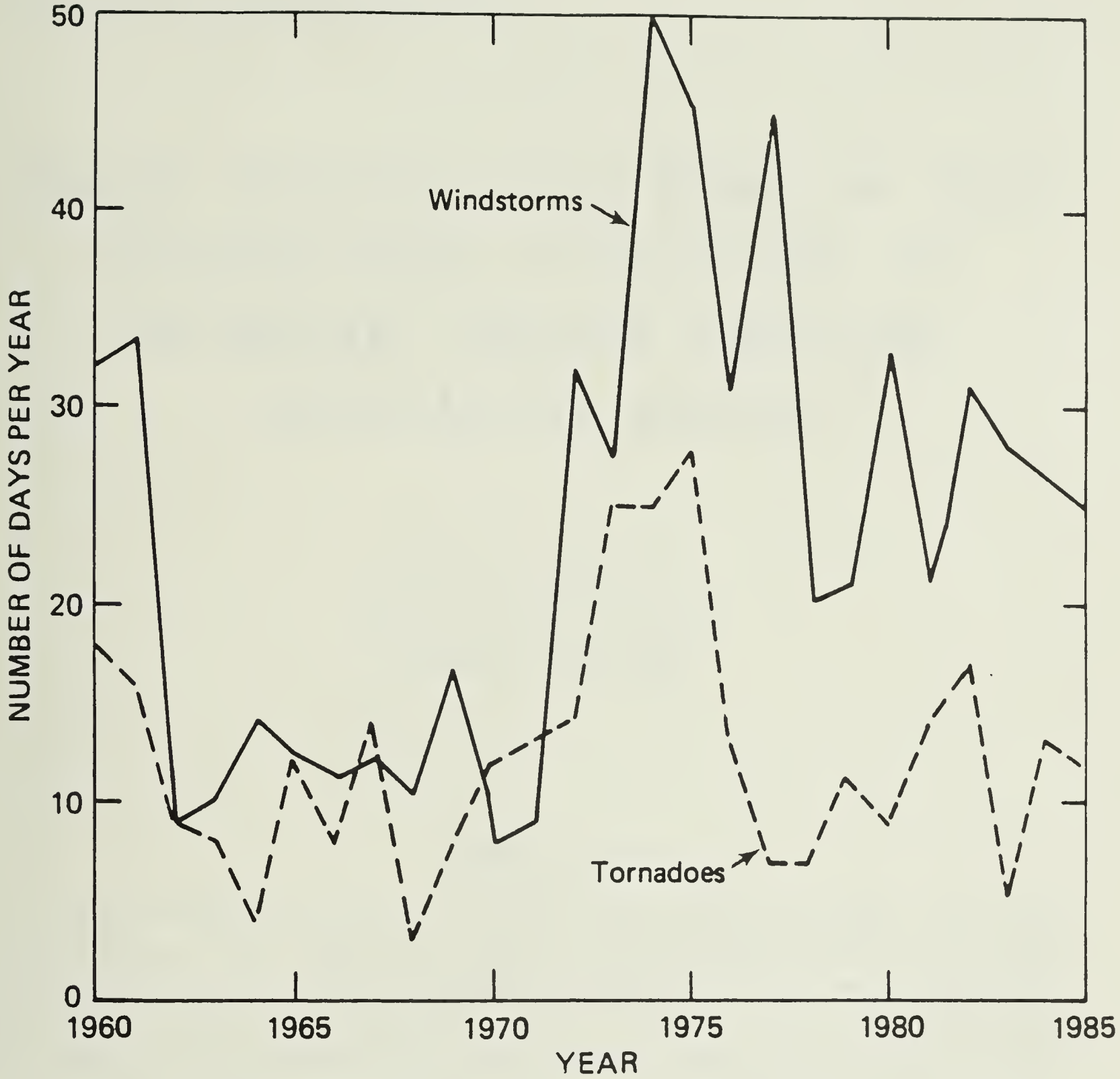

Fig. 7. Annual numbers of tornadoes and straight-line wind events from 1960 to 1985.

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SOME POSSIBLE FACTORS IN THE GEOGRAPHIC VARIATION OF ISCHEMIC HEART DISEASE MORTALITY RATES

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ABSTRACT

Regional differences exist in ischemic heart disease mortality rates in the United States. These differences appear to be partially related to geographic variations in environmental risk factors. Age-adjusted county mortality rates (sample of 101 counties) were examined as to their associations with seven environmental variables. Inverse relationships with altitude and drinking water hardness are noted while positive associations are found for atmospheric sulfur dioxide concentration, snowfall, and weather instability. A multivariate regression model was formulated and suggests that 44 percent of the variance in ischemic heart disease mortality rates can be explained by a combination of altitude, air pollution, income level, and snowfall frequency. The remaining variance may be accounted for by other environmental factors and perhaps by personal factors that may be difficult to quantify.

INTRODUCTION

Regional variations in cardiovascular disease mortality rates exist in the United States. Rates are higher in the southwestern part of the Atlantic Coastal Plain and in the Manufacturing Belt of the Northeast than they are in the Mountain States or Great Plains. Previous studies [Enterline and Stewart, 1956; Sauer, 1962; Pyle, 1971; Sauer, 1978] seem to indicate that this general pattern has remained relatively

constant over the past thirty years. It is virtually impossible to attribute such geographical differences solely to personal factors, such as genetic composition, occupation, dietary habits, tobacco, etc. [Kleinman et al., 1981; Meade, 1983]. Environmental risk factors or characteristics of place may have better explanatory value. Some of these extrinsic factors that may play roles in the etiology of ischemic heart disease are air quality, drinking water hardness, weather and climate, and socio-economic stress [Bean, 1938; Daubert, 1952; Stallones, 1965; Carroll, 1966; Schroeder and Kraemer, 1974; Rogot and Padgett, 1976; Singh et al., 1977]. Such factors are not randomly distributed in space and correlation of the spatial variation of any such variable with variation in ischemic heart disease mortality may suggest some causal relationship.

A study was undertaken to try to determine which environmental factors might explain the spatial variation of ischemic heart disease mortality rates in the United States. Environmental factors were evaluated through the construction and testing of a linear regression model that may explain the degree to which these extrinsic factors explain mortality variations.

METHODOLOGY

One hundred and one counties in the coterminous United States were selected as the sample for analysis. Because spatial contiguity presents problems of social, economic, and environmenal interaction between adjacent enumeration units, a random areal sample was chosen in a manner that would preserve geographical separation so as to avoid spatial autocorrelation and to reduce measurement errors. Ischemic heart disease (ISCN 410-413) mortality rates (mean annual rate 1976-1978) were computed for each county and age-adjusted to the 1980 U.S. population structure. These rates serve as the dependent variable.

Based upon literature review, seven environmental variables were selected. These variables are (1) Drinking Water Hardness (as ppm $CaCO_3$), (2) Mean Annual Number of Days With Snowfall Exceeding One Inch (adjusted for latitude), (3) Index of Weather Instability (annual number of days with unsettled weather), (4) Mean Elevation Above Sea Level, (5) Air Pollution (indexed by the average annual arithmetic mean concentration of sulfur dioxide [see Dzik and Cember, 1985]), (6) Median Family Income, and (7) Percentage of the Labor Force That is Unemployed.

In order to develop a predictive model, Pearson product-moment correlation coefficients were computed for each of the environmental variables and the mortality rates to determine the degree to which individual factors might be associated with the death rates. Stepwise regression was performed to obtain a regression model which might be useful in explaining geographic variation in ischemic heart disease mortality rates.

RESULTS AND DISCUSSION

Correlation coefficients are presented in Table 1. IHD mortality rates were significantly ($p < .01$) associated with five of the seven variables. Elevation exhibited the highest coefficient ($r = -.380$). Sulfur dioxide concentrations were also

moderately correlated with the mortality rates (r = + .365). An inverse relationship was found for water hardness (r = –.318). There was a positive association between mortality rates and the annual number of days with snowfall (r = + .310) and a weaker association with weather instability (r = + .296). These bivariate associations appear to be in accord with the findings of earlier studies [Daubert, 1952; Schroeder, 1960; Carroll, 1966; Dudley et al., 1969; Rogot, 1974; Singh et al., 1977; Baker-Blocker, 1982].

Ischemic heart disease death rates exhibited no significant relationships with the two socio-economic variables (unemployment and median family income), but the signs of the coefficients are in agreement with the hypotheses concerning these variables. That is not to say that the spatial variations of IHD mortality rates cannot be partly explained by these variables for there may be interactions which cannot be accounted for by simple bivariate analysis. Because none of the independent variables exists alone in space, the desired explanatory model must be multivariate.

A forward addition stepwise regression procedure was applied to the data using the Statistical Package for the Social Sciences (SPSS) computer program. Stepwise regression is one method for selecting the "best" regression equation ("Best" implies that the model is the one that produces the highest r^2 statistic, when only statistically significant coefficients are included, and also that possesses the least amount of deviation about the regression line).

The multivariate model appears in Table 2. This explanatory model uses four environmental variables, elevation, annual number of days with snowfall, median family income, and sulfur dioxide concentration, to explain 44 percent of the variance in the IHD death rates. The model suggests that higher rates are likelier to be in areas of cold climate at low elevations where there is considerable air pollution and incomes are low. The predictive power, however, is somewhat limited, as indicated by a rather wide spread about the regression line.

The relative importance of any two predictor variables in a regression model can be obtained by taking the ratio of the squares of their respective standardized regression coefficients [Kachigan, 1982]. When this method is applied to the model, elevation accounts for about 1.4 times as much of the variance as does the snowfall variable and for 3 times as much as does sulfur dioxide. The standardized regression effect [St. Leger and Sweetnam, 1979] or the percentage change in the death rate that is induced by increasing an environmental variable by one standard deviation while all other independent variables are held constant shows that elevation induces the largest change (13.1%) and sulfur dioxide the least (7.2%).

The model confirms several of the hypothesized relationships, namely that elevation, air pollution, income, and snowfall characteristics may play some part in explaining the ischemic heart disease mortality rate of a place. The relationships concerning water hardness, unemployment, and weather instability were not substantiated by the model. The statistical problem of multicollinearity could be suspected.

Multicollinearity is a condition in which several independent variables are strongly related to one another in a linear relationship. With multicollinearity it is difficult to interpret the strengths of each predictor variable. It may be that a particular variable's relevance is clouded by the presence in the model of another variable to which it is related. Tests, suggested by Kmenta [1971], indicated that multicollinearity in the variable set was not a problem.

Another question concerning the model is the unexplained variance. Factors of the physical and socio-economic environment, such as air temperature, cardiotoxins in the soil, and occupational structures (which were not evaluated in this research), are perhaps likely candidates for explaining some of the remaining variance. Part of the unexplained variance might also be related to personal risk factors that are difficult to quantify.

CONCLUSIONS

The regression model suggests that 44 percent of the variance in ischemic heart disease mortality rates in the U.S. can be explained by a combination of four environmental features. The model indicates that, on the average, IHD mortality rates will be greater in counties at low elevations, with greater frequency of heavy snowfall, with lower income levels, and with considerable air pollution than in places at higher altitude that have infrequent snowfall, higher income levels, and little air pollution.

There are, of course, some problems with using aggregate data like that utilized here, but the results of this examination lend further credence to several hypotheses concerning the epidemiology of ischemic heart disease, namely:

1. High altitude dwellers may be in some way protected from certain forms of cardiovascular disease because of their physiologic attributes that developed in response to barometric pressure conditions at higher altitudes.
2. Atmospheric contamination has an aggravating role in cardiovascular disorders as certain pollutants disrupt normal pulmonary functions, which in turn stresses the cardiovascular system.
3. Stress from poor living conditions may be a contributory factor in ischemic heart disease. Poverty itself is probably a factor as it can be a barrier to accessing preventative and curative treatment.
4. Snowfall may bring about physical strain, mental stress, and access to service problems, all of which may enhance the risk of mortality from ischemic heart disease.

With the apparent multifactorial etiology of ischemic heart disease, further research into the interactions of environmental and personal risk factors may be the key to control of this disease. Further examination of suspected high risk physical and social environments is necessary.

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Table 1. Associations between ischemic heart disease mortality rates and environmental factors.

Environmental Variable	HR*	r
Mean Elevation Above Sea Level	–	–.380**
Annual Arithmetic Mean Concentration of Sulfur Dioxide	+	.365**
Drinking Water Hardness	–	–.318**
Mean Annual Number of Days With Snowfall Exceeding One Inch (Adjusted for Latitude)	+	.310**
Weather Instability	+	.296**
Per Cent Unemployed	+	.176
Median Family Income	–	–.092

* HR = Hypothesized direction of relationship between environmental variable and IHD death rates.

** Coefficient significant at $p < .01$, N = 101.

Table 2. Regression model for ischemic heart disease death rates. Equation: $Y = 451 - 0.031X_1 + 336X_2 - 0.013X_3 + 3.43X_4$. Standard deviation of Y about the regression line: 95. $r^2 = .44$. F = 17.7 (significant at $p < .01$, N = 101).

Variable	Standardized Coefficient	t Statistic
X_1 : Mean Elevation Above Sea Level	–.470	–5.6
X_2 : Mean Annual Number of Days With Snowfall Exceeding One Inch (Adjusted for Latitude)	.394	4.6
X_3 : Median Family Income	–.370	–4.4
X_4 : Annual Arithmetic Mean Concentration of Sulfur Dioxide	.277	3.2

All coefficients significant at $p < .01$, N = 101.

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BREEDING BIOLOGY AND HABITAT OF UPLAND SANDPIPERS ON PRAIRIE-CHICKEN SANCTUARIES IN ILLINOIS

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ABSTRACT

Between 1963 and 1984, 33 upland sandpiper (*Bartramia longicauda*) nests were found while nest searching 2,940 ha of grassland on prairie-chicken (*Tympanuchus cupido*) sanctuaries in Jasper County, Illinois. Twelve of 24 nests of known fate hatched and nest success was calculated at 48% using Mayfield's (1975) method. Sandpipers selected diverse stands of grasses and forbs for nesting, and avoided fields of uniform grass and legumes. Selected vegetation heights ranged from 15-30 cm; cover over 60 cm was unsuitable. Selected brood habitat consisted of wheat stubble fields, recently hayed legumes, old redtop meadows, and moderately grazed pastures.

INTRODUCTION

During the late 1800s, thousands of upland sandpipers were slaughtered annually by market hunters. Upland sandpiper numbers dwindled until the Migratory Bird Convention Act of 1916 ended market hunting in the United States, after which populations gradually recovered (Mitchell 1967, Kirsch and Higgins 1976). Recent declines in numbers of upland sandpipers in Illinois have been attributed to decreases in habitat quality and quantity (Graber and Graber 1963).

Upland sandpipers are listed as endangered in the Illinois Endangered Species Act of 1972. According to Jurek and Leach (1977), upland sandpipers bred in 22 states and were transients in 13 other states. Its population status was listed as

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common in 12 states, and uncommon, endangered, peripheral, or irregular in 24 states; sandpiper habitat was decreasing in 11 states and static or unknown in 14 states. Upland sandpipers were not known to be increasing anywhere and there were no known improvements in habitat of significant scale. Continued degradation prompts a continuing need for information to better manage habitat that remains. The purpose of this paper is to provide information on the breeding biology of upland sandpipers in Illinois.

STUDY AREA AND METHODS

The study was conducted on sanctuaries in Jasper County, Illinois, managed as grasslands for the preservation of a local remnant flock of greater prairie-chickens (*Tympanuchus cupido pinnatus*). The sanctuaries consist of eight 7-94 ha units dispersed over nine contiguous sections. These sanctuaries are currently owned or leased for management by the Illinois Chapter of The Nature Conservancy and the Illinois Department of Conservation. Major plant cover types seeded on the sanctuaries are redtop bentgrass (*Agrostis alba*), common timothy (*Phleum pratense*), smooth brome (*Bromus inermis*), prairie grasses (*Andropogon gerardi, Panicum virgatum, Sorghastrum nutans*), legumes (*Trifolium pratense, Lespedeza stipulacea, Trifolium hybridum, Medicago sativa*), and weedy grass meadows (fields of mixed forbs and grasses). Cover is managed on an annual basis by a variable combination of prescribed burning, harvesting grass seed by combine, rotary mowing, or haying (Sanderson et al. 1973, Westemeier 1973, and Westemeier and Buhnerkempe 1983).

Nest searches in late May through August, 1963 through 1984, were primarily for finding the remains of prairie-chicken nests (Westemeier 1973, Westemeier and Buhnerkempe 1983). Active nests, including those of upland sandpipers, were checked approximately twice a week until the fate of the nest was determined. Mayfield's (1975) method was used in calculating nest success.

The log-likelihood ratio, goodness-of-fit test (Zarr 1984) was used ($P < 0.05$) to determine if the upland sandpiper showed a preference in nest habitat. Expected values for the goodness-of-fit tests were calculated by multiplying the relative proportion of a particular habitat available on the sanctuaries by the total number of nests found. Plant nomenclature follows Scott and Wasser (1980).

In 1983 and 1984, breeding censuses were conducted during late April through May to determine the number of upland-sandpiper pairs on each sanctuary unit. The censuses began 0.5 hour before sunrise and continued for approximately 3 hours. All sanctuary bounderies were walked and all sandpipers heard or seen, on and off the sanctuaries, were recorded. Censuses were limited to rainless mornings with wind speeds of less than 25 km/hr.

RESULTS AND DISCUSSION

Arrival Date

From 1963 through 1984, the earliest spring arrival date noted for an upland sandpiper on the Jasper County Prairie-chicken Sanctuaries was 6 April, 3 days earlier than the earliest arrival date at Urbana, Illinois (126 km, N), reported by

Smith (1930). The average arrival date on our study area was 10 April, and nest initiation typically began 2 weeks later during the first week of May. In Wisconsin, Ailes (1980) reported that the upland sandpiper began nesting approximately 2 weeks after spring arrival.

Nesting

Data were obtained on 33 upland sandpiper nests found while searching 2,940 ha of potential nest habitat (1 nest/90 ha). Each completed nest of known fate (n = 24) had four eggs — the typical number for clutches of the family Scolopacidae (Johnsgard 1981). Based on Kendeigh's (1963:453) definition of incubation, the incubation period for two nests was 23 days. Higgins and Kirsch (1975:99) summarized incubation periods of 21-28 days ($\bar{x}$ = 24 days) for 12 clutches reported in the literature, and their data on 9 clutches ranged from 22-27 days ($\bar{x}$ = 24 days). Sizes of 6 upland-sandpiper eggs measured on this study averaged 32.5 mm × 42.4 mm.

Of 24 nests whose fate was known, 12 hatched (50%), 11 were destroyed by mammalian predators, and one was abandoned. Buss and Hawkins (1939), Kirsch and Higgins (1976), Bowen (1976), and Kaiser (1979) reported nest success rates of 66, 65, 59, and 80%, respectively. Mayfield's (1975) method for calculating nest success was used to take into account problems of estimating nest success. We found a survival rate of 0.97 nest/day from 128 observation days of 10 active nests. Thus, because egg-laying and incubation average 28 days, the nest success was calculated to be 48%, which was similar to the observed nest success of 50%.

Egg success was calculated from eight clutches. Among 32 eggs, 29 hatched (91%), two were judged infertile, and one contained a dead embryo. Higgins and Kirsch (1975) observed that 94% of 400 upland-sandpiper eggs hatched, and Buss and Hawkins (1939) found that 97% of 101 eggs hatched.

Upland sandpipers were selective of cover types ($G = 22.55$, $P < 0.001$) (Fig. 1) used for nesting. Use of predominant redtop-timothy meadows for nesting was similar to expected; however, selection was shown for mixed grasses and forbs. No plant species were clearly dominant in the latter fields. No nests were found in fields of mixed wheat stubble-legumes.

Selection of nest habitat based on the management conducted prior to the nesting season was significantly different ($G = 52.84$, $P < 0.001$) (Fig. 2) from expected. Upland sandpipers selected fields that had been rotary mowed or burned the previous season. Grass meadows harvested for seed the previous year were used for nesting significantly less than other available grasslands. However, the number of nest seasons elapsed since a field was burned had no apparent effect on sandpiper nest densities ($G = 4.29$, $P > 0.50$). The number of nests found in undisturbed or hayed fields was not significantly different from expected. Thus, upland sandpipers did not selectively nest in fields past their first year of growth since a burn.

Selection of nest sites among the various age classes of grassy cover available on the study area was not random ($G = 38.80$, $P < 0.001$) (Fig. 3). Until 5 years after seeding, sandpipers showed little selection among fields for nesting. However, nest densities were notably higher in fields more than 5 years after seedings and especially high in sods past the eighth season of growth.

Upland sandpipers selected fields of seeded grasses being invaded by forbs for nesting; such habitat was typical of young, rotary-mowed seedings and of older grass seed meadows. Fields containing relatively uniform stands of grass (such as redtop) that had been harvested for grass seed the previous year, or those seeded to smooth brome, were rarely selected by nesting sandpipers. Kirsch and Higgins (1976) noted that 75% of upland sandpipers nests in North Dakota were in "fair cover" characterized by "stubble fields, moderately grazed pastures, mowed areas with heavy regrowth, brush clumps with some understory vegetation, and undisturbed (not mowed or grazed) vegetation on poor soils," rather than "tall, undisturbed stands of grass." Other studies have reported nests of upland sandpipers in old-field habitats (Dorio and Grewe 1979), in tuffs of grass in pastures (Bent 1929, Buss and Hawkins 1939), and in idle fields (Buss and Hawkins 1939, Meanley 1943). In Missouri, Skinner (1975) found that use of grasslands by upland sandpipers increased with a light scattering of forbs but declined drastically when forbs predominated. Higgins et al. (1969) and Buss and Hawkins (1939) found little nesting by sandpipers in relatively homogenous fields of seeded legumes. These studies, together with our findings, indicate the importance of forbs (diverse structure) in the nesting habitat of upland sandpipers.

Upland sandpipers most frequently chose habitats having a mixture of medium height, narrow-leaved grasses (redtop bentgrass, common timothy, bluegrass) and forbs for nesting (Table 1). Tall, rank prairie grasses such as big bluestem, Indian grass, and switchgrass were not found at nest sites, although fields containing these grasses occupied 15% of the area searched. Kirsch and Higgins (1976) and Kaiser (1979) also found a large proportion of the upland-sandpiper nests surrounded by short or medium height, narrow-leaved grasses, especially bluegrass (*Poa* spp.). On Illinois' largest remaining tract of native mesic tall-grass prairie (Goose Lake Prairie) upland sandpipers restricted nesting to patches of bluegrass and did not use the taller prairie grasses (Birkenholz 1973).

Upland-sandpiper nests on our study area were located in cover from 17-33 cm in height (n = 15), such as weedy fields that had been rotary mowed the previous summer or in old redtop-timothy meadows invaded with forbs and Kentucky bluegrass (*Poa pratense*). Only one nest was in a field of prairie grass, but that field had been burned the preceding winter and the vegetation was sparse and short at the time of nest initiation early in the growing season.

Upland sandpipers have been reported nesting in vegetation of the following heights: 22.5-35 cm (Dorio and Grewe 1979) and 18-35 cm (Lindmeier 1960) in Minnesota; 15-31 cm in North Dakota (Kirsch and Higgins 1976); 12-64 cm (42% of nests in cover 13-33 cm high) in South Dakota (Kaiser 1979); and nesting in fields averaging 23 cm high and feeding and loafing largely in fields 10-30 cm high in Missouri (Skinner 1975). These studies suggest that sandpipers selectively nest in cover of mixed weedy forbs and grasses ranging from about 15 through 35 cm and do not normally use cover in monotypic stands or stands that exceed 60 cm. Buss and Hawkins (1939) suggested that vegetation should be no taller than the sandpiper's back in order to provide freedom of vision. Other factors considered important to the upland sandpiper in selecting a nest site are loafing and feeding cover near the site (Buss and Hawkins 1939) and the proximity of a small shrub or tree (Dorio and Grewe 1979).

Brooding

Movements of two broods were watched during this study. By the third day after hatching, one brood had ranged up to 170 m from the nest site. The other brood had traveled up to 410 m from the nest site by the fifth day after hatching. Dorio and Grewe (1979) observed one upland sandpiper brood move 297 m in two days and another move 495 m in four days.

At Bogota, broods were observed primarily in fields of wheat stubble (n = 13), recently hayed legumes (n = 10), old and weedy redtop (n = 10), and on moderately grazed pastures (n = 10). Upland-sandpiper broods also use old fields and overgrazed pastures (Dorio and Grewe 1979) and often feed in newly mowed hay fields (Buss and Hawkins 1939). Good brood habitat appears to be short (< 20 cm), open, and weedy; such cover facilitates movements of the chicks and offers an abundance of insects for food. Once the brood reaches an "acceptable" brooding area, daily movements are short (< 100 m) and within 20 ha. Broods were generally found within an area of 20-40 ha (Ailes 1980).

Population Status

The apparent decline of upland-sandpiper nest densities on the prairie-chicken sanctuaries in Jasper County over the past 20 years (Fig. 4) is of concern even though samples are small. Recent censuses on the prairie-chicken sanctuaries in Jasper County, Illinois, showed 8 breeding pairs in 1983 and 7 pairs in 1984 — about one pair per 40.5 ha of grassland. The increased availability of managed grasslands suitable for breeding sandpipers from 12 ha in 1963 to 72 ha in 1984 has not effectively altered the decline. Whether the decline can be attributed to habitat conditions surrounding the sanctuaries or to regional declines in numbers of upland sandpiper is unclear. The gradual decline in upland-sandpiper numbers in Ohio since the 1920's has been attributed to the loss of grassland habitat (Osborne and Peterson 1984).

On the basis of this study, seeding and management of cool-season introduced grasses, such as bluegrass, redtop, and timothy appear beneficial to upland sandpipers when given time to age (5+ years) and diversify. To promote diverse mixtures of grasses and forbs, such seedings should be allowed to reach 10-12 years of age before reseeding. Management of seeded fields of the above grasses may include a 3-year rotation of rotary mowing to a height of 15-30 cm, no disturbance, and prescribed burning. Moderate grazing of cool-season grasses and prairie grass would also provide suitable nesting and brooding cover, but further research on grazing under Illinois conditions is needed. Mowing of likely sandpiper nest-brood habitat, if necessary, should be delayed until 1 July or later if possible, to avoid losses of eggs and young.

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Table 1. Vegetation occurring <25 cm from the rim of the nest bowl of 23 upland-sandpiper nest sites from 1963-83 on the Jasper County Prairie-Chicken Sanctuaries in Illinois. The dominant was the species with the greatest proportion of stems.

Plant Species	Frequency of Occurrence	Dominant at Nest Site
Redtop Bentgrass (*Agrostis alba*)	13	7
Common Timothy (*Phleum pratense*)	11	7
Brome (*Bromus* spp.)	8	2
Goldenrod (*Solidago* spp.)	7	2
Aster (*Aster* spp.)	6	1
Bluegrass (*Poa* spp.)	5	2
Ragweed (*Ambrosia* spp.)	5	0
Common Yarrow (*Achillea millefolium*)	5	0
Fleabane (*Erigeron* spp.)	3	0
Carolina Horse-nettle (*Solanum carolinense*)	3	0
Lettuce (*Lactuca* spp.)	2	1
Flowering Euphorbia (*Euphorbia corollata*)	2	0
Rush (*Juncus* spp.)	2	0
Fescue (*Festuca* spp.)	1	1
Alfalfa (*Medicago sativa*)	1	0
Black-eyed Susan (*Rudbeckia hirta*)	1	0
Buckhorn Plantain (*Plantago lanceolata*)	1	0
Common Dandelion (*Taraxacum officinale*)	1	0
Yellow wood-sorrel (*Oxalis dillenii*)	1	0
Deptford pink (*Dianthus armeria*)	1	0
Northern Dewberry (*Rubus flagellaris*)	1	0
Milkweed (*Asclepias*) spp.	1	0
Mountainmint (*Pycnanthemun* spp.)	1	0
Ox-eye Daisy (*Chrysanthemum leucanthemum*)	1	0
Panicum (*Panicum* spp.)	1	0
Prairie-dock (*Silphium terebinthinaceum*)	1	0
Red clover (*Trifolium pratense*)	1	0
Sweetclover (*Melilotus* spp.)	1	0
Grasses	20	13
Forbs	18	10

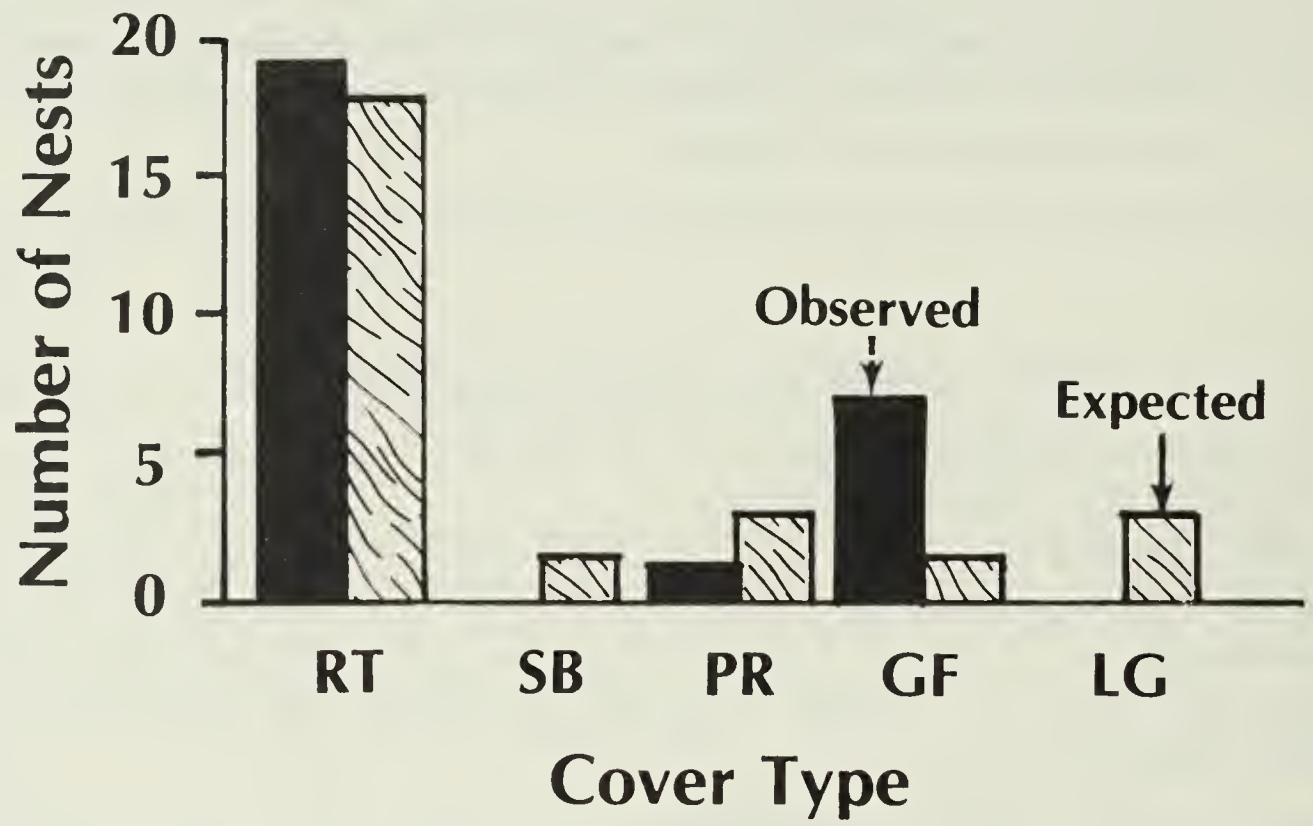

Figure 1

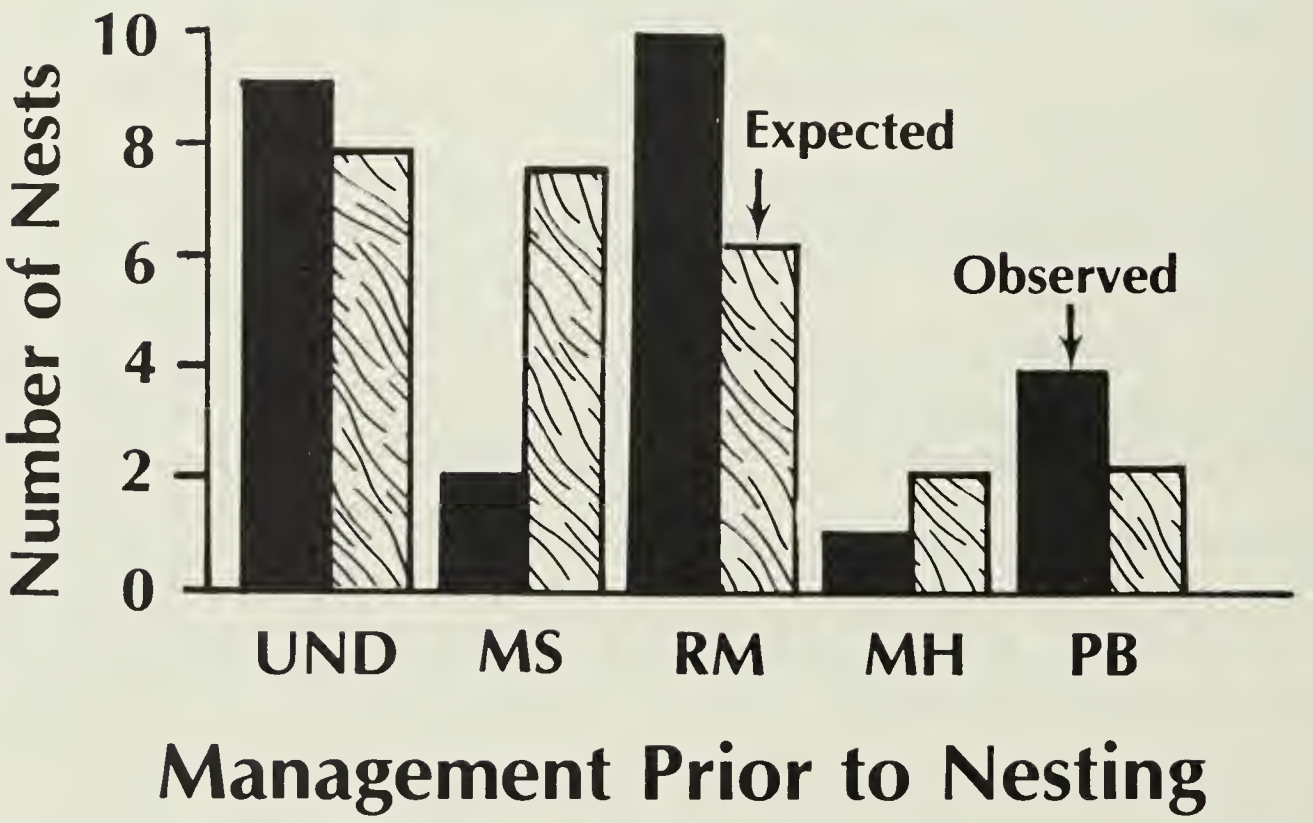

Figure 2

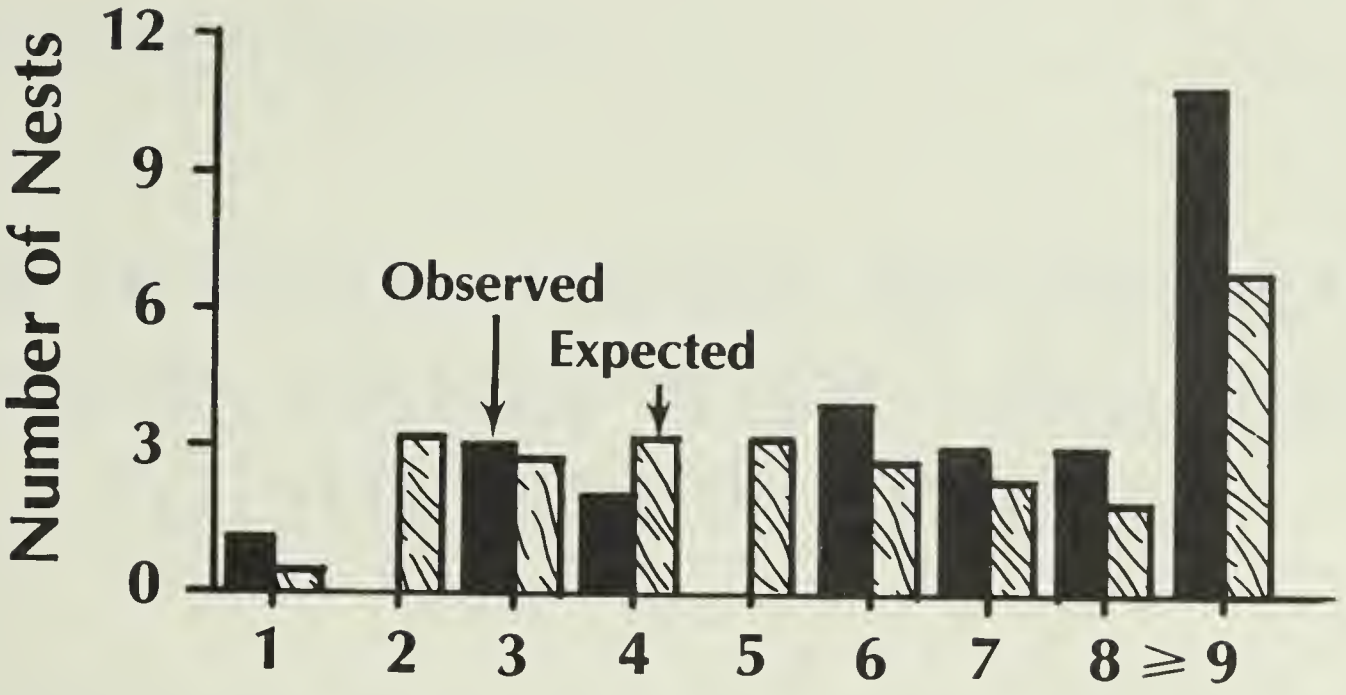

Figure 3

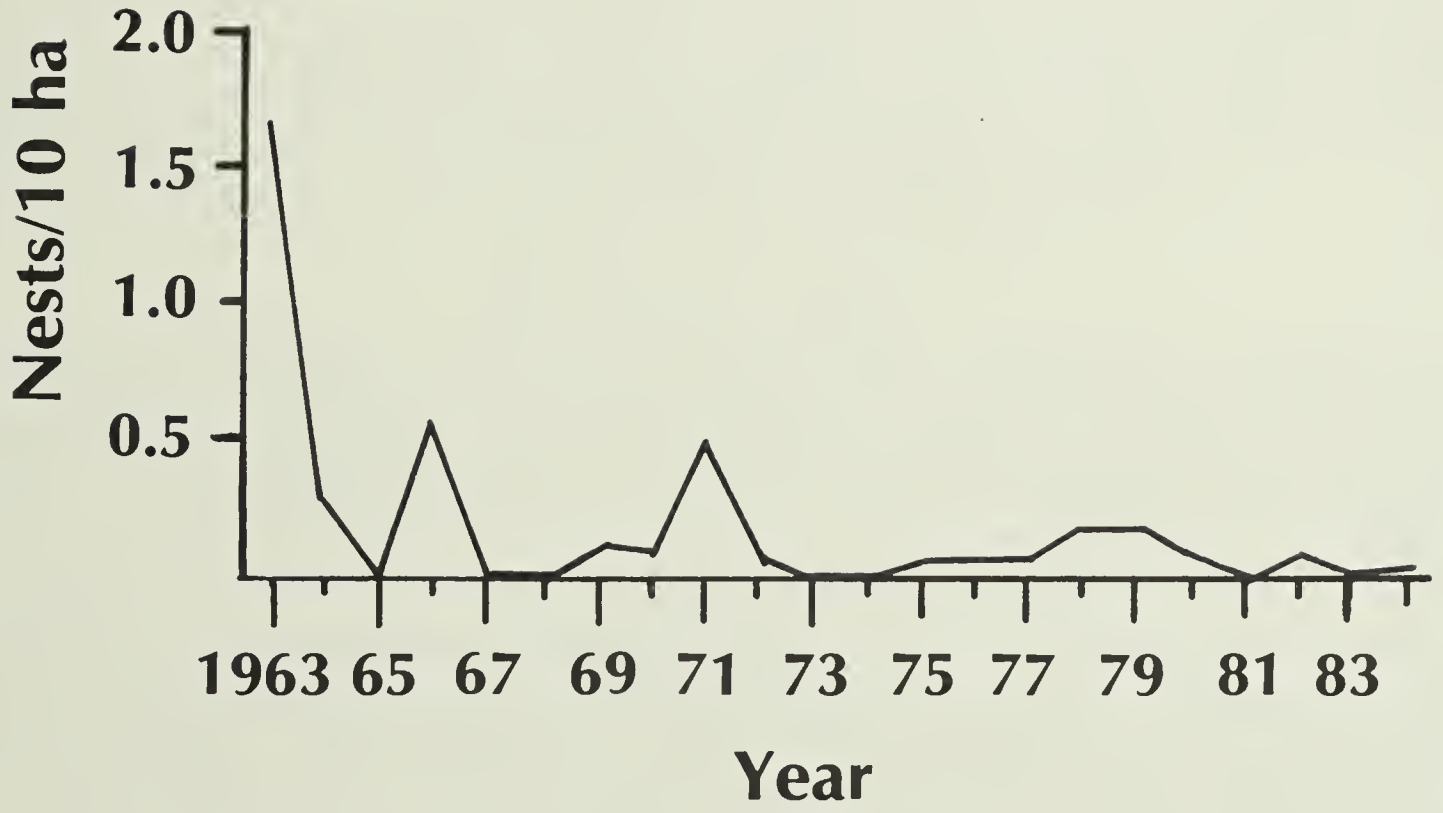

Figure 4

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NEW DISTRIBUTIONAL RECORDS OF ILLINOIS FISHES WITH ADDITIONS TO THE KNOWN FAUNA

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ABSTRACT

Through recent Illinois fish surveys and examination of fish collections made in the late 1930s and early 1940s, two fishes, the taillight shiner (*Notropis maculatus*) and inland silverside (*Menidia beryllina*), are added to the faunal list of the state; in addition, new localities are reported for nine other species. A record of the Atlantic salmon (*Salmo salar*) from the Mississippi River is also reported. In light of these new records, the taillight shiner, inland silverside, and spotted sunfish (*Lepomis punctatus*) require conservation status evaluations by the Endangered Species Protection Board and its Technical Advisory Committee on Fishes.

INTRODUCTION

Nearly ten years have passed since Smith (1979) published his comprehensive work on the fishes of Illinois. His review of the state fish fauna revealed 199 species (the discovery of *Menidia beryllina* after the book was completed is mentioned in a footnote on p. 211). Since then, collectors have rediscovered the greater redhorse, *Moxostoma valenciennesi* (Seegert 1986), a species thought to have been extirpated from Illinois. Examinations of collections made prior to Smith's survey have documented previously unreported records for the cypress minnow, *Hybognathus hayi* (Burr and Mayden 1982), bluehead shiner, *Notropis hubbsi* (Burr and Warren 1986a), and pallid shiner, *Notropis amnis* (Warren and Burr 1988). An introduced fish, the rainbow smelt, *Osmerus mordax*, has recently and rapidly extended its range in Illinois (Burr and Mayden 1980).

Recent field work, particularly in southern Illinois waters, has revealed the presence of one alien and two native species not previously reported. Several new distributional records for nine rare or uncommonly encountered fishes also were discovered through field work and examination of Illinois fish collections at the University of Michigan Museum of Zoology.

The purpose of this paper is to report records of 12 fishes, all of which have limited or unusual ranges in Illinois, so that informed evaluations of their conservation status can be made by the Illinois Endangered Species Protection Board and its Technical Advisory Committee on Fishes.

ACCOUNTS OF SPECIES

Records are based on several collections made by the authors and collections deposited at the Illinois Natural History Survey (INHS), Southern Illinois University at Carbondale (SIUC), University of Michigan Museum of Zoology (UMMZ), and Illinois Department of Conservation (IDOC). Species accounts include catalog number, locality, major drainage, county, date of collection, and in parentheses, the number of specimens. Genera and species are treated alphabetically within the general phylogenetic scheme presented by Robins et al. (1980).

Acipenser fulvescens Rafinesque
Lake Sturgeon

SIUC 15529, Mississippi River (Gulf of Mexico dr.) in Pool 14 below tailwaters of Lock and Dam 13, Whiteside County, 29 September 1978 (1); IDOC uncat., Mississippi River (Gulf of Mexico dr.) at Chain of Rocks, Madison County, 7 or 8 November 1987 (1).

Remarks: The lake sturgeon is rare in Illinois and is represented in collections by few extant specimens. To our knowledge the species has not been reported from the Mississippi River of Illinois since 1966 (Smith 1979), although a recent (1977) record is available from the Mississippi River of Kentucky (Warren et al. 1986). The Illinois specimens weighed approximately 18 and 50 lbs.; the SIUC specimen was tagged on the right side of the dorsal fin, but the tag was partially destroyed and illegible. Given the mobility of the species, we presume these individuals are waifs from populations in the upper Mississippi River or possibly the Missouri River (Pflieger 1975). The lake sturgeon is presently recognized as a state threatened species.

Lepisosteus oculatus (Winchell)
Spotted Gar

SIUC 12766, Rend Lake (Big Muddy R. dr.), Franklin/Jefferson counties, 13 September 1983 (4); SIUC 14697, Black Lake (Ohio R. dr.), 4.8 km. NE Old Shawneetown, Gallatin County, 22 May 1986 (1); SIUC 15313, Loon Lake (Ohio R. dr.), 2.75 km. SSE Brookport, Massac County, 13-14 July 1987 (1); SIUC 14470, Big Grande Pierre Creek (Ohio R. dr.), ca. 1.6 km. upstream from mouth, 8 km. NE Golconda, Pope County, 7 October 1986 (1); SIUC 14469, Lusk Creek (Ohio R. dr.), near Golconda, Pope County, 22 April 1987 (2); SIUC 15416, Barren Creek (Ohio R.

dr.), 2.4 km. upstream from mouth, ca. 1.6 km. W Bay City, Pope County, 17 October 1986 (1); SIUC 15333, Old River (Wabash R. dr.), 7 km. SE Emma, White County, 22 July 1987 (1).

Remarks: Records reported here extend the range of the spotted gar to southeastern Illinois and the Big Muddy River drainage. Smith (1979) reported no records from the southeastern borders of the state, including the Wabash River drainage, although the species is known from adjacent southwestern Indiana (Lee and Wiley 1980) and western Kentucky (Burr and Warren 1986b).

Salmo salar Linnaeus
Atlantic Salmon

SIUC 12967, Mississippi River (Gulf of Mexico dr.), near Chester, Randolph County, February 1986 (1).

Remarks: Previously unreported and not known to be legally stocked anywhere in the main Mississippi River, this species is native to the North Atlantic Ocean and adjacent coastal streams and was stocked on several occasions in the 1970s in Lakes Superior and Michigan (Becker 1983); however, Smith (1979) did not report the species from the Illinois portion of Lake Michigan. Over 30 Atlantic salmon were captured by commercial fisherman Roger Norfolk and one was frozen by Illinois Department of Conservation Biologist Francis Imboden and later transferred to SIUC. The specimen, a female, 555 mm in standard length, contains mature ova. The provenance and potential survival of this species in Mississippi River waters is unknown.

Nocomis micropogon (Cope)
River Chub

SIUC 15043, Little Vermilion River (Wabash R. dr.), 8 km. SE Georgetown, Vermilion County, 28 June 1987 (3); INHS 63435, Little Vermilion River (Wabash R. dr.), 3.2 km. N Hamrick, Vermilion County, 6 August 1987 (2).

Remarks: Smith (1979) recorded only two localities of the river chub in Illinois: the Wabash River proper in Clark and Lawrence counties. The locality reported here is the third record of the river chub for the state but more importantly also represents the only potential breeding population known in Illinois. The Little Vermilion River contains abundant nesting habitat for the species. The river chub recently was recommended for inclusion on the state watch list.

Notropis emiliae (Hay)
Pugnose Minnow

SIUC 15305, Beaver Pond (Wabash R. dr.), 3.7 km. SE New Haven, Gallatin County, 21 July 1987 (1); SIUC 15236, Long Pond (Ohio R. dr.), 7 km. NE Old Shawneetown, Gallatin County, 16 July 1987 (7); SIUC 15249, Big Lake (Ohio R. dr.), 4.5 km. NE Old Shawneetown, Gallatin County, 16 July 1987 (13); SIUC 14701, Black Lake (Ohio R. dr.), 4.8 km. NE Old Shawneetown, Gallatin County, 22 May 1986 (2); SIUC 15277, unnamed wetland between Big Lake and Fish Lake, 4.5 km. NE Old Shawneetown, Gallatin County, 16 July 1987 (1); SIUC 14416, Peters

Creek (Ohio R. dr.), 2.4 km. upstream from mouth, 2.4 km. SW (town of) Peters Creek, Hardin County, 14 October 1986 (1); SIUC 15273, Allard Lake (Ohio R. dr.), 2.5 km. N Paducah, Kentucky, Massac County, 14 July 1987 (2); SIUC 15357, unnamed wetland (Ohio R. dr.), 2.25 km. S Unionville at Devil's Washboard, Massac County, 31 July 1987 (3); SIUC 15315, Loon Lake (Ohio R. dr.), 2.75 km. SSE Brookport, Massac County, 13-14 July 1987 (12); SIUC 15229, Beaverdam Lake (Ohio R. dr.), 6.75 km. ESE Unionville, Massac County, 15 July 1987 (26); SIUC 15293, unnamed lake (Ohio R. dr.), near mouth of Bay Creek, 7 km. SSE Homberg, Pope County, 13 July 1987 (40); SIUC 14574, Three Mile Creek (Ohio R. dr.), 1.6 km. upstream from mouth, ca. 4.0 km. W Rosiclaire, Pope County, 27 October 1986 (2); SIUC 14549, Big Grande Pierre Creek (Ohio R. dr.), 3.2 km. upstream from mouth, 2.4 km. W Shetlerville, Pope County, 7 October 1986 (3); SIUC 13006, Limekiln Slough (Cache R. dr.), 3.2 km. SSW Perks, Pulaski County, 2 July 1986 (38); SIUC 13118, Long Reach (Cache R. dr.), 2 km. SSE Perks, Pulaski County, 13 May 1986 (1); SIUC 15322, Brushy Slough (Wabash R. dr.), 3.25 km. ENE New Haven, White County, 21 July 1987 (10); SIUC 14077, Lake of Egypt (S. Fk. Saline-Ohio R. dr.), Williamson/Johnson counties, 29 April 1980 (5).

Remarks: Smith (1979) regarded the pugnose minnow as extremely sporadic and rare in much of Illinois and noted its decline in the face of drainage and siltation in the southern third of the state. The collections cited above include the first records for the Cache River system and indicate that the species is common in streams, lakes, and wetlands along the Ohio and extreme lower Wabash rivers.

Notropis maculatus (Hay)
Taillight Shiner

SIUC 15282, unnamed wetland (Ohio R. dr.), 2.25 km. S Unionville at Devil's Washboard, Massac County, 15 July 1987 (1); SIUC 15356, same locality, 31 July 1987 (6).

Remarks: This locality represents the first record of this fish from Illinois, the most upstream record of the species in the Ohio River basin, and the northernmost limit of its range. The taillight shiner is a Coastal Plain species, and its northern distributional limits were believed to be in northwestern Kentucky, where its range abuts the Ohio River (Burr and Warren 1986b). In a recent ichthyofaunal survey (Burr and Warren 1987) of 22 lakes or wetlands along the lower Ohio and Wabash rivers, the taillight shiner was captured only at the locality cited above. The presence of young-of-the-year individuals at the site indicates that recent reproduction has taken place. The possibility exists that the taillight shiner persists in one of several of the lakes in the area but was missed in our sampling, or it has recently expanded its range. Alternatively and ironically, the taillight shiner may have been discovered in Illinois on the brink of extirpation. The species should be recognized as a state endangered species, and this population given highest priority for protection.

Erimyzon sucetta (Lacepède)
Lake Chubsucker

SIUC 15263, Yellowbank Slough (Wabash R. dr.), 4.8 km. S New Haven, Gallatin

County, 17 July 1987 (13); SIUC 8268, slough at Oakwood Bottoms (Big Muddy R. dr.), 8 km. NE Grand Tower, Jackson County, 29 November 1978 (1); SIUC 8267, LaRue-Pine Hills Swamp (Clear Cr.-Mississippi R. dr.), Union County, 9 June 1952 (1).

Remarks: No modern records for the lake chubsucker have been reported from the southern half of Illinois (Smith 1979). Gunning and Lewis (1956) reported it from a strip-mine pond in Perry County; this record is probably the result of introduction. Wall and Gilbert (1980) mapped numerous Illinois locations for the species in their account in the *Atlas of North American Freshwater Fishes*. Unfortunately, the localities plotted on their distribution map represent a composite of both the lake chubsucker and its close and widespread relative the creek chubsucker, *Erimyzon oblongus*. Smith (1979) mentioned records at UMMZ from various localities in southern Illinois. To the best of our knowledge, the only records from Illinois of the genus *Erimyzon* at the UMMZ are based on the creek chubsucker. Despite having made many collections in presumably suitable habitat in southern Illinois, we were unable to document other localities of occurrence for the species. Specimens from Yellowbank Slough were young-of-the-year, a finding that indicates successful reproduction has recently occurred.

Percopsis omiscomaycus (Walbaum)
Trout-perch

UMMZ 130274, Little Kincaid Creek (Big Muddy R. dr.), 9.6 km. S Oraville, Jackson County, 20 September 1939 (2); UMMZ 130321, Big Kincaid Creek (Big Muddy R. dr.), 16 km. S Oraville, Jackson County, 20 September 1939 (15).

Remarks: According to Smith's (1979) data, the trout-perch does not occur south of the Illinois River in Illinois. The localities reported here indicate that the species occurred in the past at least as far south as the Big Muddy River drainage. Both Kincaid Creek sites are now impounded by Lake Kincaid, and the species probably no longer occurs there. One of the above records is shown on the trout-perch distribution map in the *Atlas of North American Freshwater Fishes* (Gilbert and Lee 1980a).

Menidia beryllina (Cope)
Inland Silverside

INHS 26962, Mississippi River (Gulf of Mexico dr.), at Grand Tower near Devil's Backbone State Park, Jackson County, 8 April 1978 (1).

Remarks: This is the first record of this fish from Illinois waters and represents the northernmost locality of occurrence in the Mississippi River. Prior to this record the inland silverside was known only as far north in the Mississippi River as near Cairo (Pflieger 1975, Gilbert and Lee 1980b). Beginning in 1980 this fish has been stocked as a forage species in Baldwin Lake, Randolph/St. Clair counties; Lake of Egypt, Jackson/Williamson counties; and Rend Lake, Franklin/Jefferson counties (Stoeckel 1984, Roy C. Heidinger, pers. comm.). We presume the Mississippi River record is not the result of introduction, especially because the species is known to occur naturally in the river, and the collection was made prior to any known

introduction in Illinois. In ten years of intermittent sampling at Grand Tower, no additional specimens of the inland silverside have been captured.

Lepomis punctatus (Valenciennes)
Spotted Sunfish

SIUC 15266, Yellowbank Slough (Wabash R. dr.), 4.8 km. S New Haven, Gallatin County, 17 July 1987 (1); SIUC 14435, Goose Pond (Wabash R. dr.), 4.8 km. S New Haven, Gallatin County, 25 June 1986 (2); SIUC 15309, Beaver Pond (Wabash R. dr.), 3.7 km. SE New Haven, Gallatin County, 21 July 1987 (1); SIUC 14434, Black Lake (Ohio R. dr.), 4.8 km. NE Old Shawneetown, Gallatin County, 22 May 1986 (1); SIUC 15257, Big Lake (Ohio R. dr.), 4.5 km. NE Old Shawneetown, Gallatin County, 16 July 1987 (1); SIUC 15241, Long Pond (Ohio R. dr.), 7 km. NE Old Shawneetown, Gallatin County, 16 July 1987 (1); SIUC 15234, Beaverdam Lake (Ohio R. dr.), 6.75 km. ESE Unionville, Massac County, 15 July 1987 (6); SIUC 15321, Loon Lake (Ohio R. dr.), 2.75 km. SSE Brookport, Massac County, 13-14 July 1987 (5); SIUC 2609, Long Reach (Cache R. dr.), 2.4 km. S Perks, Pulaski County, 27 October 1979 (1); SIUC 15328, Brushy Slough (Wabash R. dr.), 3.25 km. ENE New Haven, White County, 21 July 1987 (4).

Remarks: Smith (1979) depicted few modern records for the spotted sunfish in the state and specifically noted declines in abundance in the Wabash River drainage. The localities cited here include the first record of the spotted sunfish for the Cache River and indicate that the species persists in several lakes and wetlands of the Ohio and lower Wabash rivers. This species was recently recommended for state threatened status, but in light of the records reported here, its status should be reconsidered.

Lepomis symmetricus Forbes
Bantam Sunfish

SIUC 5209, Horseshoe Lake (Cache R. dr.), at the spillway, ca. 4.8 km. SW Unity, Alexander County, 10 April 1982 (3); SIUC 5094, same locality, 17 April 1982 (4); SIUC 5128, same locality, 28 April 1982 (1); SIUC 5108, same locality, 1 May 1982 (1); SIUC 5290, Running Lake Ditch (Clear Cr.-Mississippi R. dr.), 3.2 km. S Ware, Union County, 3 April 1982 (6); SIUC 5028, Clear Creek (Mississippi R. dr.), 3.2 km. E Reynoldsville, Union County, 30 April 1982 (2).

Remarks: These records extend the Illinois range of the bantam sunfish south through the Clear Creek drainage to Horseshoe Lake. Previous to this report, modern Illinois records of the species included only Pine Hills and Wolf Lake in Union County (Smith 1979). The records from Horseshoe Lake are surprising in light of the numerous collections made at the spillway for many years by several independent investigators. The bantam sunfish is presently considered a state threatened species. The banded pygmy sunfish, *Elassoma zonatum*, was taken syntopically with the bantam sunfish on several occasions in Horseshoe Lake, a new Illinois locality for *E. zonatum*.

Percina sciera (Swain)
Dusky Darter

UMMZ 214130, Cache River (Ohio R. dr.), 2.4 km. S Unity, Alexander/Pulaski County lines, 5 October 1940 (1); UMMZ 214131, 3.2-4.8 km. NE Unity, Alexander/Pulaski County lines, 5 October 1940 (7); SIUC 14462, Ohio River (Mississippi R. dr.), 2.4-5.6 km. downstream from Golconda, Pope County, 20 October 1986 (1); SIUC 14502, Bay Creek (Ohio R. dr.), 2.4 km. upstream from mouth, 3.2-4.8 km. NW Bay City, Pope County, 24 September 1986 (1); UMMZ 214129, Post Creek Cut Off (Cache-Ohio R. dr.), 1.6 km. E Karnak, Pulaski County, 1 September 1940 (1).

Remarks: The dusky darter was previously believed to be restricted to the Vermilion, Embarras, and Little Wabash rivers in Illinois (Smith 1979). The records reported here extend its range to the southern third of the state in the Cache and Ohio rivers and some of their tributaries. Given the distribution of the species across the Ohio River in western Kentucky (Burr and Warren 1986b), these additional records were predictable. Recent records (1986) show that dusky darters are still present in Pope County streams, but recent attempts to collect this species from the Cache River were unsuccessful (Phillippi et al. 1986).

DISCUSSION

The discovery of the taillight shiner, inland silverside, and Atlantic salmon in Illinois waters brings the total number of species known from the state to 202. The presence of young-of-the-year taillight shiners in our collections demonstrates that recent reproduction has occurred. The inland silverside does not appear to have maintained a viable natural population in Illinois waters, but introductions into Baldwin Lake and Lake of Egypt are judged successful because of evidence of overwintering in these thermally enriched environments (Roy C. Heidinger, pers. comm.). The provenance and potential survival of the Atlantic salmon in the Mississippi River is unknown, and unless the introduced Lake Michigan stock shows evidence of reproduction and recruitment, the species should probably not be considered part of the Illinois fauna.

In light of the new records reported here, we recommend that the taillight shiner be recognized as endangered in Illinois and that the proposed threatened status of the spotted sunfish be reconsidered. Because we do not know of a viable native population of the inland silverside in Illinois, we recommend that it not be included on state conservation lists.

Important new records for otherwise poorly known Illinois fish species (e.g., cypress minnow [Burr and Mayden 1982], bluehead shiner [Burr and Warren 1986a], pallid shiner [Warren and Burr 1988], greater redhorse [Seegert 1986]) have materialized recently as a result of intensive collecting and examination of historical collections excluded from Smith's (1979) study. While many Illinois fishes show clear-cut evidence of range reduction, others are expanding their ranges, and still others are being introduced into Illinois waters. Because of the dynamic nature of the Illinois fish fauna (Smith 1979), we urge continued collection of fishes even in presumably well-surveyed areas.

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FEEDING RELATIONSHIPS AMONG FOUR RIFFLE-INHABITING STREAM FISHES

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ABSTRACT

The diel feeding period, dietary composition, and prey size relative to fish size were compared between four riffle-inhabiting stream fishes, *Cottus carolinae* (banded sculpin), *Etheostoma caeruleum* (rainbow darter), *E. flabellare* (fantail darter), and *E. spectabile* (orangethroat darter) in Illinois. The darters exhibited similar diurnal feeding patterns, while *Cottus* showed a crepuscular feeding pattern. Diet compositions of the darters were more similar to each other than to *Cottus*, based on cluster analysis of percentage similarity measures. These data also suggested that feeding habitat may differ in stream flow, with *Cottus* being the most rheophyllic, decreasing in the darters, *E. flabellare* and *E. caeruleum*, and *E. spectabile* having the most lentic diet. Significant but weak correlations were found between prey size and fish gape width in all fish species. The correlation was strongest in *Cottus*, which has the broadest fish size range of the four species examined. This suggests that in natural populations with naturally broad body size variation, prey size and fish size may be strongly correlated, allowing effective food resource partitioning among species and size classes within species.

INTRODUCTION

The study presented here was conducted to investigate the extent of overlap in resource utilization, particularly feeding period, prey size, and dietary composition among four small coexisting freshwater stream fishes. These species, including three darters (Percidae) and the banded sculpin (Cottidae), occur syntopically in riffle habitats of cool upland streams throughout much of the highland region of the eastern U.S. (Lee et al. 1980). Much literature has accumulated over the years on the biology of darters, including two recent books on their systematics and biology

(Page 1983, Kuehne and Barbour 1983). Several studies have been conducted on the food and feeding behavior of various darter species (e.g., Forbes 1880, Turner 1921, Winn 1958, Scalet 1972, Schenck and Whiteside 1977), including many life history studies which contain food habit information (Page 1983 and references therein). However, relatively little information has been published on the feeding periodicity and comparative feeding relationships of syntopic species (Mathur 1973, Adamson and Wissing 1977, Smart and Gee 1979, Cordes and Page 1980, Bek and Surat 1982, Matthews et al. 1982, Paine et al. 1982, Hlohowskyj and White 1983). Less information is available on the biology and feeding habits of freshwater sculpins (Koster 1937, Bailey 1952, Zarbock 1952, Northcote 1954, Daiber 1956, Patten 1962, Minckley et al. 1963, Straskraba et al. 1966, Pasch and Lyford 1972, Novak and Estes 1974, Mason and Machidori 1976, Daniels and Moyle 1978), which often co-inhabit cool, rocky riffles with darters in areas of range overlap.

In this study the diel feeding relationships of 4 riffle-inhabiting fish species were investigated in Hutchins Creek in southern Illinois. Species studied are the rainbow darter (*Etheostoma caeruleum*), fantail darter (*E. flabellare*), orange-throat darter (*E. spectabile*), and banded sculpin (*Cottus carolinae*). Diel feeding periodicities, diet compositions and prey size relative to fish size were determined for each species and compared between species. At the study area these species and the slender madtom (*Noturus exilis*) represent the riffle ichthyofauna. Trophic habits of the nocturnal *N. exilis* were presented earlier by Mayden and Burr (1981).

Study Site

Hutchins Creek is a 3rd order spring-fed stream draining primarily oak-hickory forests, with some pastured and cultivated land within the watershed. Stream habitats include gravel riffles and gravel and slate-bedded pools separated by gravel raceways. Stream width ranges from 1.5 to 7.5 m; water depth from 4 cm in riffles to about 2 m in pools. Annual stream temperatures range from 1° C in January to 32° C in July. Stream flow is continuous. The sample site consisted of two consecutive riffle areas (approx. 2.4 m × 3.6 m each and approx. 30 m apart), located 4 mi NW of Anna; SW ¼ of Sec. 25, R3W, T11S, Union Co., Illinois.

Materials and Methods

About five specimens each of *C. carolinae*, *E. caeruleum*, *E. flabellare* and *E. spectabile* were collected every 2 hr over a 24-hr period 27-28 September 1979 (Fig. 1). Fishes were killed in 10% formalin and preserved in 70% ethyl alcohol. In the laboratory the standard length (SL) and gape width (GW) of each fish were recorded. Gape width was measured as the transverse distance across the oral groove, with mouth closed (Hubbs and Lagler 1947). Stomach contents of each fish were examined, food items identified and maximum lengths and widths measured on intact food items using an ocular micrometer. Animal food items were identified to lowest possible taxon. Numeric indices describing the degree of digestion of food in stomachs (1-5; 1 indicating least, 5 indicating most, digestion) and degree of fullness of stomach (1-5; 1 = least, 5 = most, full) were assigned to each fish. The latter index used stomach distention and relative thickness of the stomach wall as indicators of fullness.

Dietary composition was compared between fish species by calculating percentage similarity indices followed by dendrogram cluster analysis (CLUSTAN,

Wishart 1978) based upon the percentage similarities. Percentage similarity among diets of each fish species was calculated using the following equation:

$$PS = 1 - 0.5 \sum_{i=1}^{S} | (p_{ai} - p_{bi}) | = \sum_{i=1}^{S} \min (p_{ai} \text{ or } p_{bi})$$

where p_a is the proportion of the total diet of fish species *a* comprised by a prey species, p_b is the proportion of the diet of fish species *b* comprised by the same prey species, and *s* is the total number of prey species common to both diets (Schoener and Gorman 1968, Linton et al. 1981). Taxonomic richness (number of species) of diet was also compared between fish species.

Data were tested for univariate normality using N-scores correlation analysis of normality as described by Ryan et al. (1980). Appropriately transformed data were then tested for significant differences in mean size of food items between fish species using two-sample t-test. Prey and fish size data were tested for significant relationship within species using correlation analysis. Fish gape width and standard length relationships were explored using linear regression.

Results and Discussion

Body size. — A combined total of 229 specimens of the 4 fish species were examined (Table 1). *Cottus carolinae* was the largest species examined with the broadest range for SL and GW, while *Etheostoma caeruleum, E. flabellare* and *E. spectabile* were very similar in size and range of both measurements (Table 1). Relationships between standard length and gape width of the darter species and *Cottus* were also dissimilar. At a given body length, all darter species had a similar gape width, which was less than one-half the gape width of a *Cottus* of that length (comparisons based on linear regressions using data summarized in Table 1). Equations describing the linear relationship between GW and SL are: *Cottus* GW = −2.92 + .244 SL, R^2 = .871; *E. caeruleum* GW = −1.16 + .096 SL, R^2 = .672; *E. flabellare* GW = −.547 + .0847 SL, R^2 = .775; *E. spectabile* GW = −.628 + .0929 SL, R^2 = .867. All linear regressions of gape width on standard length were significant ($p < .001$ for all species).

Diel feeding periodicity. — Mean number of food items found in stomachs of fish of each species collected over 24 hr are presented in Figure 1. Based upon this measure, the three darters exhibited diurnal feeding activity patterns (Fig. 1), while *Cottus carolinae* showed a primarily crepuscular feeding pattern (Fig. 1A). Mean stomach fullness index (Fig. 2) and mean food digestion index (Fig. 3) corroborate these interpretations of feeding activity in most cases. Stomach fullness shows a positive correlation with number of prey ingested in *C. carolinae* (Figs. 1A, 2A), *E. caeruleum* (Figs. 1B, 2B), and *E. spectabile* (Figs. 1D, 2D), however, no clear pattern is exhibited in the fullness index curve of *E. flabellare* (Fig. 2C). Generally, mean digestion index (Fig. 3) was negatively correlated with food abundance (Fig. 1) and stomach fullness (Fig. 2), though not strongly so except in *C. carolinae* (Figs. 1A, 2A, 3A). The strong dip between 1600 hr and 2200 hr in the latter species' mean digestion curve (Fig. 3A), coupled with pronounced rise in fullness from 1800-2400 hr (Fig. 2A), suggests that highest feeding activity may occur in the evening in this species. Comparing the feeding periodicities of these riffle-inhabiting species with *Noturus exilis* (Mayden and Burr 1981), *C. carolinae* shows strong overlap in time of

feeding. Both species exhibit greatest activity during crepuscular periods of the diel cycle.

Diet comparisons: composition. — A total of 25 prey taxa occurred in the stomachs of all fish species combined (Table 2). Chironomid larvae were by far the most important food item in the diets of the darters, but were less important than the mayfly nymph, *Centroptilum*, in the diet of *Cottus*. The diet of *Cottus* also differed from those of the darter species in the absence of microcrustacea and the presence of fish (*Campostoma anomalum*). Percentage similarities of diet composition (Table 3) compared using dendrogram cluster analysis (Fig. 4) again illustrate the similarity in diets of the *Etheostoma* species, primarily due to the dominance of chironomid larvae. Dietary similarity among darters is probably exaggerated by the lack of resolution in this prey group. *Cottus* was much less similar in diet to each darter species (Table 3) and all darters as a group (Fig. 4A) than the darters were to each other.

Differences between the sculpin and the darters in time of feeding and/or microhabitat within riffles may account for two diet dissimilarities (Chironomidae, *Centroptilum*). Differences between the darters and sculpin in gill raker morphology most likely explains the dietary dissimilarity in the number of microcrustacea consumed. In fact, the 3 darter species have very similar number and arrangement of gill rakers, with 10-15 well-developed rakers on the first gill arch. *Cottus* has reduced gill rakers (nubs) on the first gill arch and so is not equipped to filter small food items. The presence of fish prey (*Campostoma anomalum*) in the diet of the sculpin, and the absence of such prey in the darters, most likely reflects differences between the sculpin and darters in maximum size. Fish were present only in the diets of the largest *Cottus* individuals (59.0-72.6 mm SL), larger than the largest individuals of any of the *Etheostoma* species examined. Figure 4A also shows *E. flabellare* to be less similar in diet to the other darter species than they are to each other, which reflects the greater importance of *Cheumatopsyche* and *Centroptilum* in the diets of *E. flabellare* and *Cottus*. Thus, *Cottus* and *E. flabellare* may at times feed in similar microhabitats, perhaps more rheic than the other darters, given the highly rheophyllic habits of *Cheumatopsyche* (Merritt and Cummins 1978).

To refine comparison between the diets of the darters, percentage similarities were calculated between them, excluding Chironomidae (Table 3) and these values were used in dendrogram cluster analysis (Fig. 4B). *Etheostoma caeruleum* and *E. flabellare* were more similar in diet to each other than either was to *E. spectabile* (Table 3, Fig. 4b). This most strongly reflects the high proportion of the more lentic taxa such as Cladocera, Copepoda, Ostracoda and Ceratopogonidae (Merritt and Cummins 1978, Pennak 1978) in the diet of *E. spectabile* relative to the other darters (Table 2). Further, the highly rheophyllic caddisfly larva, *Cheumatopsyche* was found in a much lower proportion in the diet of *E. spectabile* than the other darters. The more lentic diet of *E. spectabile* may be explained by its broad habitat use, including stream pools as well as riffles and riffle margins, compared to *E. flabellare* and *E. caeruleum* which are restricted to riffle habitats (Cross 1967, Pflieger 1975, Smith 1979).

One inference that can be drawn from the above diet comparisons is that during this study period the four species varied in feeding habitat from *Cottus* being most rheophyllic, followed by *E. flabellare* and *E. caeruleum*, to the more lentic *E. spectabile*. The diet of *Noturus exilis* (Mayden and Burr 1981) shows

similarity to all of the species studied here, but is especially similar to *C. carolinae* and *E. flabellare* in the high number of Ephemeroptera and rheophyllic Trichoptera (*Cheumatopsyche*) present in the gut. This suggests that the slender madtom may also inhabit the more rheic microhabitats while feeding. Page (1983) suggests that feeding microhabitat may be the primary cause of dietary separations among darter species. However, experimental tests of this hypothesis are generally lacking in published food habit studies.

Comparisons of taxonomic richness of diet (S) are presented in Table 2. The low S value for *Cottus* relative to the darters again most strongly reflects general fish species size and gill raker morphology. *Cottus* generally cannot retain microcrustacea and other characteristically or seasonally small organisms, which effectively reduces the potential taxonomic richness of its diet compared to the darters. Differences in S between the darters most likely reflects behavioral and feeding microhabitat differences between species.

Diet comparisons: prey size. — A total of 1,124 food items from the 4 fish species was measured (Table 1). Log-transformed prey maximum widths and fish gape widths were tested by two-sample t-test between fish species (Table 4). Mean prey width was much larger in *Cottus* than any of the darters, corresponding to the much larger mean gape width in *Cottus* (Table 4). Among the darters there was no difference in mean gape widths, but mean size of prey of *E. flabellare* was significantly larger than that of either *E. spectabile* or *E. caeruleum* (Table 4). Mean prey size of the latter species did not differ significantly. Because of the very large sample sizes of measured food items (Table 1), the tests were sensitive to slight consistent differences between species (less than 1 mm, see Table 1). It was therefore difficult to interpret the biological significance (if any) of the prey size differences between darter species. Comparisons between *Cottus* and darters, however, likely reveal biologically significant fish and associated prey size differences, which may be important in resource partitioning among these species.

The results of correlation analysis of prey width (PW) and prey length (PL) each with gape width within each fish species are as follows: *E. caeruleum*, Correlation Coefficient$_{PW}$ (CC_{PW}) = 0.15, $p < 0.01$, CC_{PL} = 0.10, $p = 0.05$; *E. flabellare*, $CC_{PW} = 0.19$, $p < 0.01$, $CC_{PL} = 0.27$, $p < 0.01$; *E. spectabile*, $CC_{PW} = 0.22$, $p < 0.001$, $CC_{PL} = 0.32$, $p < 0.001$; *C. carolinae*, $CC_{PW} = 0.52$, $p < 0.001$, $CC_{PL} = 0.51$, $p < 0.001$. Although statistically significant correlations between gape width and prey width, and gape width and prey length, are indicated for all fish species, the correlations are generally very weak. *Cottus* shows the best correlation between food size and gape width, which may reflect the greater size range of *Cottus* collected compared to the darter species (see Table 1), making the trend between predator and prey size more apparent. These results suggest that in natural populations with naturally broad body size variation, size of food consumed may be strongly correlated with size of feeding individual. This intuitively logical relationship sets up a food availability gradient that may be important in resource partitioning within and between some fish species. Although predator-prey size relationships are thought to have potential importance in the coexistence of similar predator species (Schoener 1974, Hespenheid 1975 and references therein) relatively few fish studies have addressed this question (Northcote 1954, Werner 1974, Mathur 1977, Ross 1977, Schenck and Whiteside 1977, Gatz 1979a, 1979b, 1981, Mathews 1982, Mathews et al. 1982, Miller 1983). Several of these studies (Gatz 1979a, 1979b,

1981, Matthews 1982) have demonstrated that morphological characters may be important variables in defining resource use patterns between gross fish community functional groups (e.g., trophic guilds, habitat guilds). Others (Ross 1977, Schenck and Whiteside 1977, Matthews et al. 1982, Miller 1984) have indicated that morphological characters, especially mouth and head size, may be important in defining within-guild resource partitioning. Miller (1984) cautions, however, that the relative position of a fish population on the resource use axis can change seasonally, due to asynchronous demographic patterns in the populations within the community (e.g. reproduction, which lowers the mean gape size of a fish population during a given season). For this reason, the resource use patterns described here for *E. caeruleum*, *E. flabellare*, *E. spectabile*, and *C. carolinae* are more comparable with similar studies conducted during the fall than other seasons.

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Table 1. Total number of specimens and morphometric means and ranges for *Cottus carolinae*, *Etheostoma caeruleum*, *E. flabellare*, and *E. spectabile* and their prey.

	Fish Species			
Measurement	*C. carolinae*	*E. caeruleum*	*E. flabellare*	*E. spectabile*
No. of Specimens	57	61	62	49
Standard length (mm)				
range	24.5-72.6	31.7-50.8	26.0-40.9	24.5-47.5
mean	39.7	40.2	35.4	33.6
Gape Width (mm)				
range	1.7-15.3	1.7-4.4	1.7-3.2	1.7-4.2
mean	6.8	2.7	2.5	2.4
No. Food Items				
total	332	1320	627	978
measured	68	460	228	368
Prey Length (mm)				
range	0.96-48.00	0.16-6.32	0.18-8.96	0.14-13.60
mean	4.58	1.57	1.82	1.33
Prey Width (mm)				
range	0.16-9.60	0.08-3.84	0.12-1.60	0.08-1.36
mean	1.24	0.29	0.34	0.28

Table 2. Total diet determined from stomach contents of all specimens of *Cottus carolinae*, *Etheostoma caeruleum*, *E. flabellare*, and *E. spectabile*, including total number of each prey taxon, percentage of total prey abundance that each prey taxon comprises, and prey taxonomic richness (S) in the diet of each fish species.

	Fish Species							
	C. carolinae		*E. caeruleum*		*E. flabellare*		*E. spectabile*	
Prey Taxon	No.	%	No.	%	No.	%	No.	%
Cladocera	0	0.0	3	0.2	2	0.3	48	4.8
Copepoda	0	0.0	3	0.2	3	0.5	51	5.2
Ostracoda	0	0.0	1	0.1	0	0.0	8	0.8
Hydracarina	0	0.0	50	3.8	25	3.9	61	6.2
Ephemeroptera								
Baetidae								
Centroptilum sp.	164	49.4	44	3.3	80	12.5	20	2.0
Heptageniidae								
Stenonema tripunctatum	1	0.3	1	0.1	2	0.3	2	0.2
Caenidae								
Caenis spp.	1	0.3	12	0.9	6	0.9	18	1.8
Plecoptera								
Perlidae								
Neoperla clymene	2	0.6	2	2.2	2	0.3	0	0.0
Coleoptera								
Psphenidae								
Psphenus herriki	16	4.8	3	0.2	1	0.2	16	0.2
Megaloptera								
Corydalidae								
Corydalus cornutus	0	0.0	0	0.0	0	0.0	1	0.1
Diptera								
Tipulidae	0	0.0	1	0.1	0	0.0	0	0.0
Psychodidae								
Pericoma sp.	0	0.0	0	0.0	0	0.0	1	0.1
Ceratopogonidae								
Atrichopogon sp.	0	0.0	1	0.1	0	0.0	1	0.1
Palpomyia	0	0.0	2	0.2	0	0.0	3	0.3
Stilobezzia	0	0.0	0	0.0	0	0.0	6	0.6
Simuliidae	2	0.6	3	0.2	7	1.1	2	0.2
Chironomidae	115	34.6	1139	86.3	467	72.9	739	74.7
Tabanidae								
Tabanus sp.	0	0.0	0	0.0	1	0.2	0	0.0
Empididae	0	0.0	3	0.2	0	0.0	0	0.0
Dipteran pupae	3	0.9	35	2.9	8	1.2	13	1.3

Trichoptera								
Hydropsychidae								
Cheumatopyche sp.	25	7.5	16	1.2	37	5.8	5	0.5
Hydroptilidae								
Hydroptila hamata	0	0.0	1	0.1	0	0.0	0	0.0
Gastropoda								
Ferrisidae								
Ferrissia sp.	0	0.0	1	0.1	1	0.2	0	0.0
Physidae								
Physa sp.	0	0.0	0	0.0	1	0.2	8	0.8
Osteichthyes								
Cyprinidae								
Campostoma anomalum	3	0.9	0	0.0	0	0.0	0	0.0
Total	332	100.0	1322	100.0	642	100.0	989	100.0
Taxonomic Richness (S)	10		20		15		18	

Table 3. Percentage similarity of diet between riffle-inhabiting fishes. Lower half of table inclusive of all species and prey taxa. Upper half calculated between darter species only, with Chironomidae excluded from diets.

	Fish Species			
Fish Species	*C. carolinae*	*E. caeruleum*	*E. flabellare*	*E. spectabile*
C. carolinae	____			
E. caeruleum	40.77	____	62.12	53.28
E. flabellare	55.05	84.27	____	38.83
E. spectabile	38.97	84.50	83.06	____

Table 4. Results from two-sample t-tests comparing gape widths (upper half of table) and prey maximum width (lower half) among four riffle-inhabiting fish species.

	Fish Species			
Fish Species	*C. carolinae*	*E. caeruleum*	*E. flabellare*	*E. spectabile*
C. carolinae	____	****	****	****
E. caeruleum	****	____	n.s.	n.s.
E. flabellare	****	*	____	n.s.
E. spectabile	****	n.s.	***	____

*p <0.05
***p <0.001
****p <0.0001

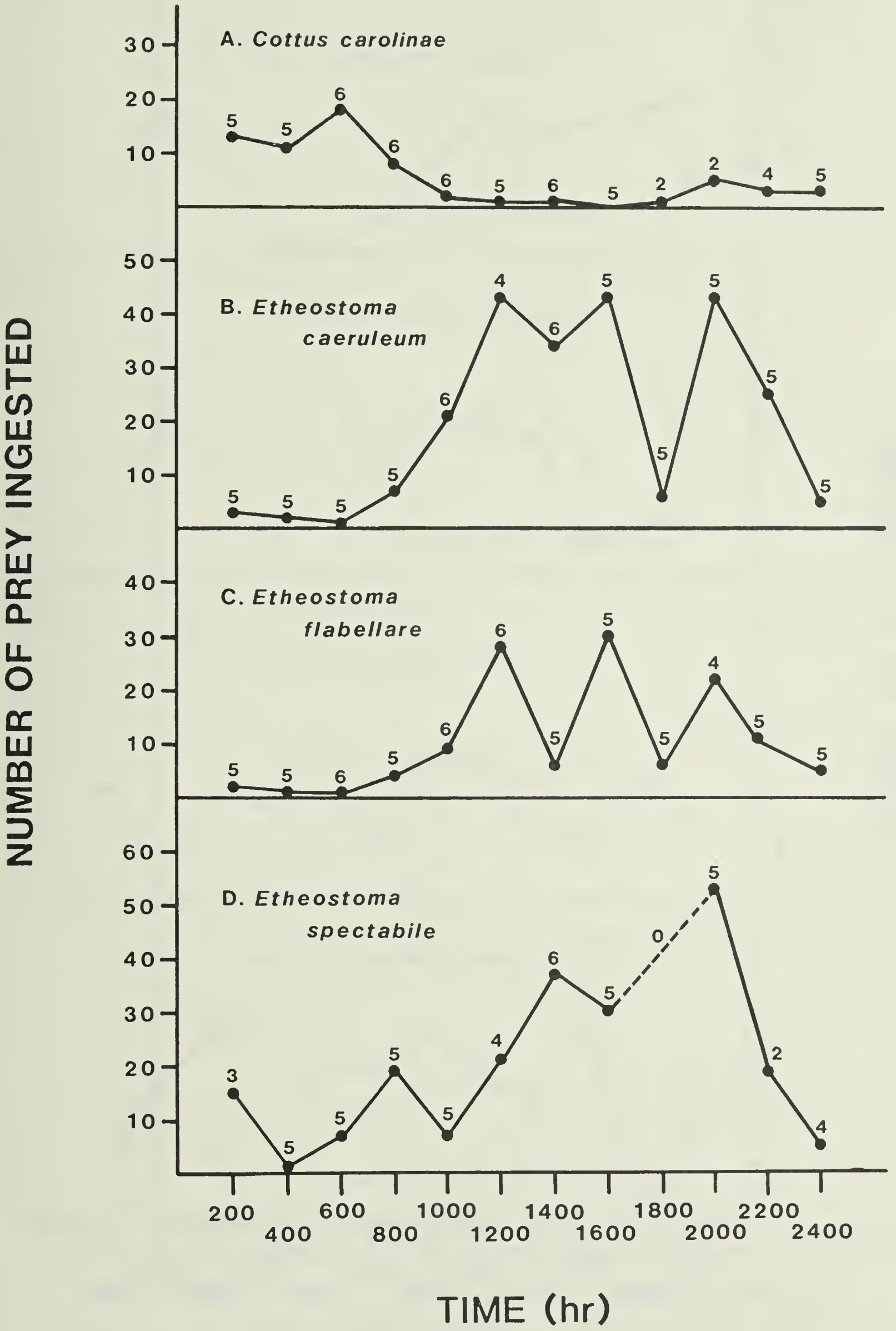

Figure 1. Mean number of food items found in the stomachs of fish collected from Hutchins Creek, Illinois, every two hr for 24 hr, 27-28 September 1979. Numbers above each collection time along the species curves represent number of fish collected at that time.

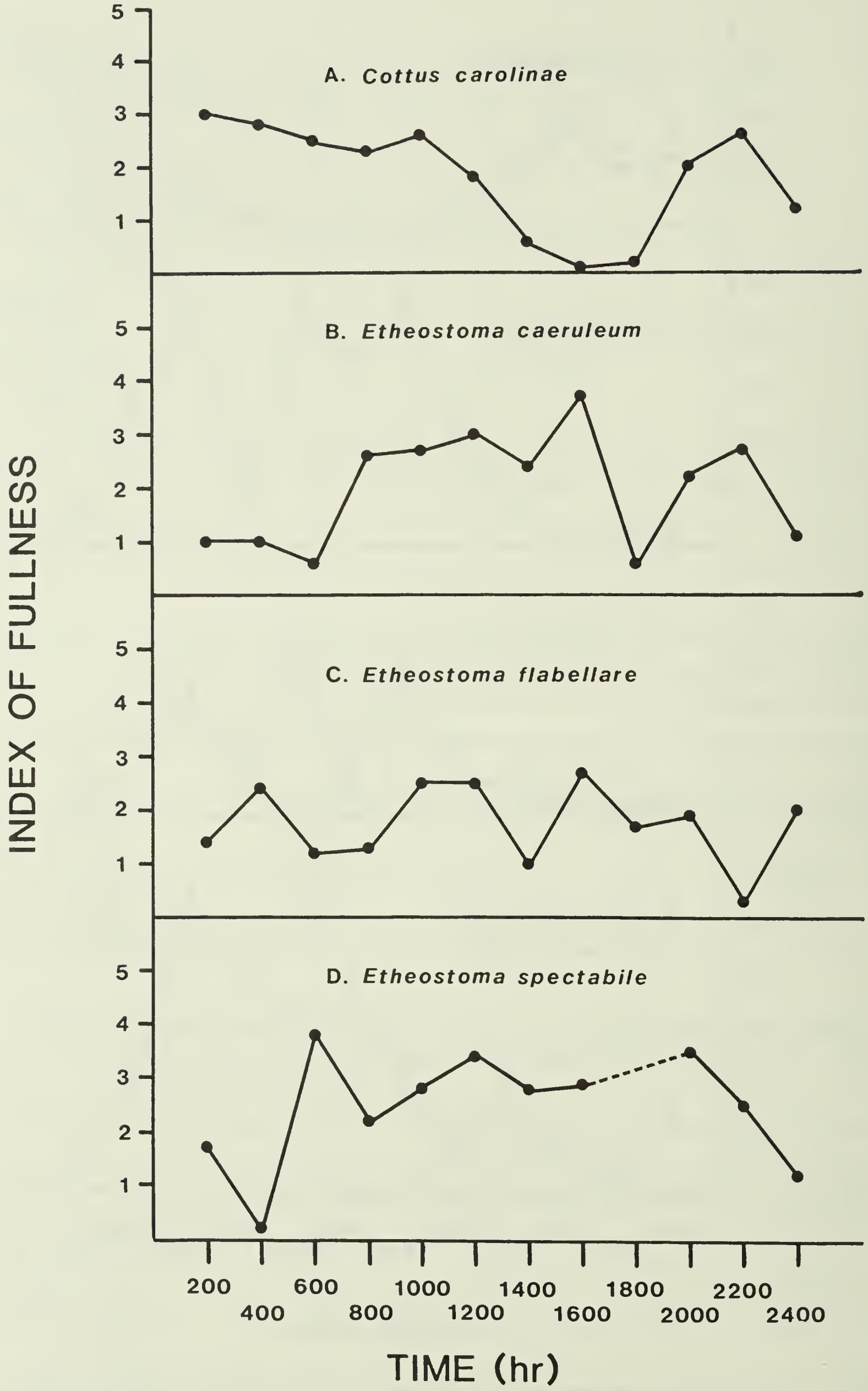

Figure 2. Mean stomach fullness index of four fish species collected every two hr for 24 hr from Hutchins Creek, Illinois, 27-28 September 1979. A fullness index of 1 indicates least full (empty) and 5 indicates most full.

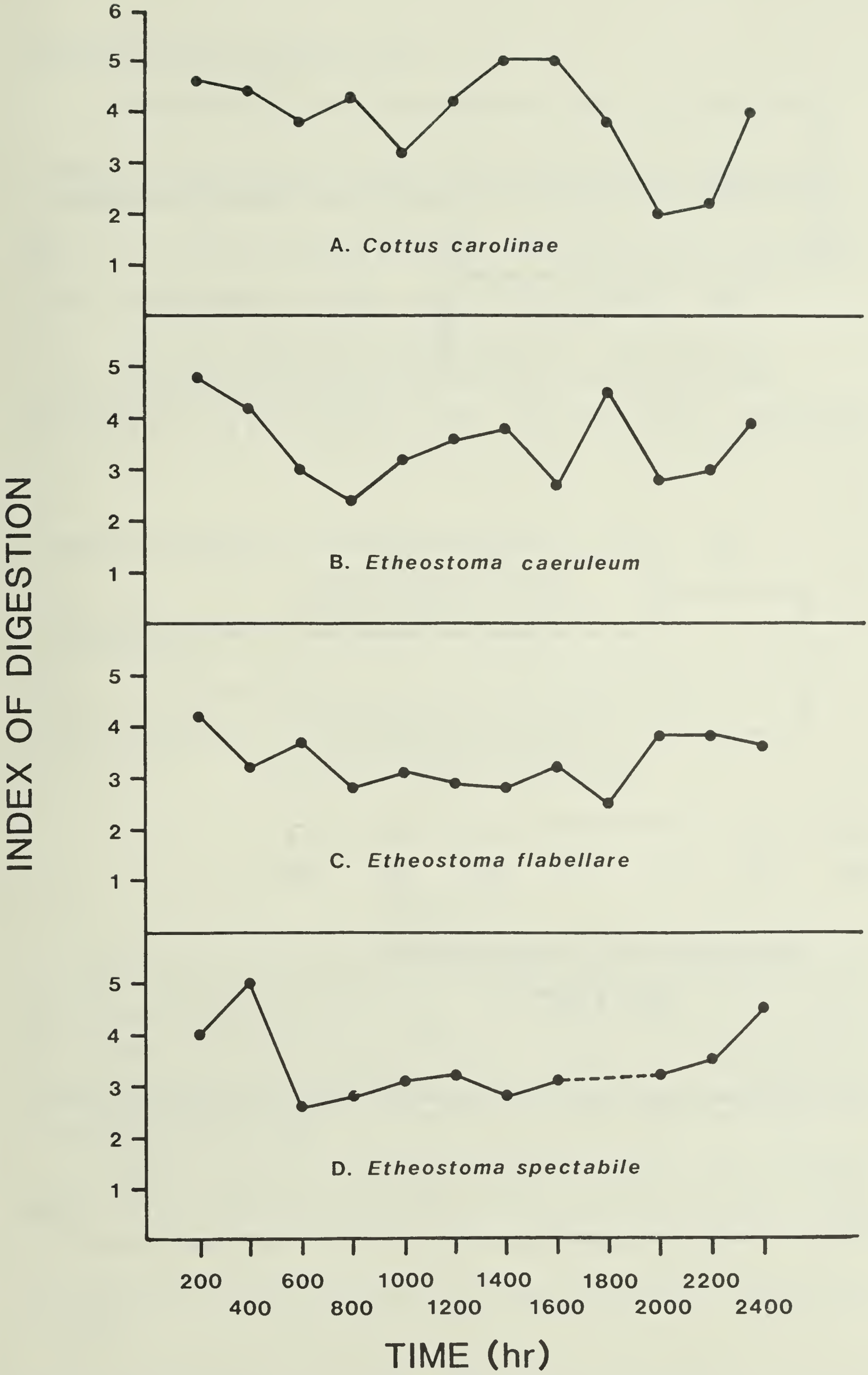

Figure 3. Mean index of digestion of stomach contents of four fish species collected every two hr for 24 hr from Hutchins Creek, Illinois, 27-28 September 1979. A digestion index of 1 indicates least apparent digestion and 5 indicates most apparent digestion of stomach contents.

Figure 4. Dendrogram cluster analysis of diet composition of (A) all four riffle fish species, and, (B) the darter species only, excluding the chironomid prey component from the analysis.

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PSEUDOPECOELUS SESOKOENSIS SP. N. (TREMATODA: OPECOELIDAE) FROM THE INTESTINE OF PLECTORHYNCHUS PICTUS (VALENCIENNES) OF OKINAWA, JAPAN

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ABSTRACT

Pseudopecoelus sesokoensis sp. n. is described from *Plectorhynchus pictus* of Sosokojima, Motobu-cho, Okinawa, Japan. It differs from other species of *Pseudopecoelus* except *P. maomao* Yamaguti, 1970, from *Abudefduf abdominalis* of Hawaii in having unlobed gonads, vitellaria not extending anterior to the acetabulum, and a pendunculated acetabulum without lateral notches. It differs from *P. maomao* in having an acetabulum larger than the oral sucker and vitellaria uninterrupted at the testicular level.

During the course of a study of the parasites of marine fishes of Ryukyu Islands, Japan, 2 specimens representing the genus *Pseudopecoelus* von Wicklen, 1946, were detected in the intestine of 1 of 4 *Plectorhynchus pictus* taken off the north coast of Sesokojima, Motobu-cho, Okinawa. Based on comparison with other

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species of *Pseudopecoelus,* the specimens are considered to be new species which is described herein.

MATERIALS AND METHODS

Four *Plectorhynchus pictus* were taken by means of spearfishing off the north coast of Sesokojima, Motobu-cho, Okinawa during July, 1985. Fishes were kept alive in plastic bags containing seawater and transported to the laboratory where the containers were placed in a refrigerator. Live specimens were removed from the fish within a few hours.

Flukes were washed in 0.7% saline, fixed in warm AFA and stored in 70% ethanol plus 2% glycerin. Specimens were stained with Harris' hematoxlin, dehydrated, cleared in beechwood creosote, and mounted in Canada balsam. Measurements are in micrometers unless otherwise indicated. The drawing was made with the aid of a camera lucida.

DESCRIPTION

Opecoelidae Ozaki, 1925
Opecoelinae Stunkard, 1931
Pseudopecoelus von Wicklen, 1946
Pseudopecoelus sesokoensis sp. n.
(Fig. 1)

Specific description: Measurements based on two whole mounts. With characters of the genus. Body elongate, subcylindrical, tapering anteriorly, 1.2-1.4 mm long, 0.2 mm wide. Oral sucker ventroterminal, 81-95 long, 80-84 wide. Acetabulum in anterior one-third of body, pendunculated, nonpapillated, 200-220 long, 132-150 wide. Prepharynx short, 8-12 long. Pharynx oval, 40-44 long, 48-50 wide. Esophagus short, 6-8 long. Cecal bifurcation near anterior edge of peduncle; ceca termination blindly near posterior end of body. Testes, intercecal, oval, smooth, tandem, anterior testis equatorial, median or slightly sinistral, 130-136 long, 106-115 wide; posterior testis median, 132-134 long, 110-117 wide. Posttesticular space 320-330 long. Seminal vesicle saccular, somewhat curved to one side, 96-120 long, 46-50 wide, postacetabular, reaching slightly beyond end of middle one-third of body. Pars prostatica and cirrus sac not evident. Cirrus short and muscular. Genital pore sinistral at level of pharynx. Ovary smooth, subglobular, situated immediately in front of and slightly dextral to anterior testis, 50-53 long, 49-51 wide. Seminal receptacle absent. Uterus preovarian, winding foreward, passing alongside of seminal vesicle, metraterm muscular, approximately equal in length to cirrus. Eggs oval, 53-62 long, 37-40 wide. Vitellaria commencing just anterior to seminal vesicle, extending uninterrupted to posterior end of body. Excretory pore terminal, excretory vesicle tubular, extending from excretory pore to posterior level of ovary.

Type host: *Plectorhynchus pictus* (Valenciennes) (Perciformes: Pomadasyidae)

Anatomical location: intestine

Type locality: North coast of Sesokojima, Motobu-cho, Okinawa, Ryukyu Islands, Japan, 26° 38′N, 127° 52′E; depth 60 ft., large coral heads.

Type specimen: USNM Helm. Coll. holotype no. 79503.

Etymology: The specific epithet *sesokoensis* refers to the geographic locality of the host and parasite.

DISCUSSION

Manter (1954) described *Pseudopecoelus hemilobatus* from *Cyttus australis* of New Zealand and included a key to the species of *Pseudopecoelus* differentiating *P. hemilobatus, P. umbrinae* Manter and Van Cleave, 1951, *P. brevivesiculatus* Hanson, 1955, *P. vulgaris* (Manter, 1934), *P. japonicus* (Yamaguti, 1938), *P. gibbonsiae* Manter and Van Cleave, 1951, *P. elongatus* (Yamaguti, 1938), *P. priacanthi* (MacCallum 1921), *P. barkeri* Hanson, 1950, and *P. tortugae* von Wicklen, 1946. More recently, Yamaguti (1970) described *Pseudopecoelus acanthuri* from *Acanthurus sandvicensis, P. puhipaka* from *Gymnothorax flavimarginatus, P. maomao* from *Abudefduf abdominalis* and *P. sphyraenae* from *Sphyraena barracuda* of Hawaii and provided a key to the species of *Pseudopecoelus* from Hawaiian fishes. A review of the literature reveals several species of *Pseudopecoelus* described since the publications of Manter (1954), namely: *P. manteri* Sogandares-Bernal and Hutton, 1959, *P. gymnothoracis* Nahhas and Cable, 1964, *P. minutus* Nahhas and Cable, 1964, *P. holocentri* Nahhas and Cable, 1964, *P. vitellozonatus* Pritchard, 1966, *P. scorpaenae* (Manter, 1947), *P. ghanensis* Fischthal and Thomas, 1970, *P. pyriformis* Prudhoe and Bray, 1973, *P. scomberi* (Hafeezullah, 1971), *P. littoralis* Caballero Y C and Caballero R., 1976, *P. nossamani* Kruse, 1977, *P. pritchardae* Gupta and Sehgal, 1979, *P. epinepheli* Wang, 1982, and *P. ariusi* Parukhin, 1983. Thus, twenty-eight species of *Pseudopecoelus* have been reported.

Pseudopecoelus sesokoensis sp. n. differs from other species in this genus except *P. maomao* Yamaguti, 1970, from *Abudefduf abdominalis* of Hawaii in having unlobed ovary and testes, a predunculated acetabulum without lateral notches, and vitellaria not extending anterior to the acetabulum. It differs from *P. maomao* in having an acetabulum larger than the oral sucker and vitellaria uninterrupted opposite to the testes.

ACKNOWLEDGMENTS

Special thanks to Dr. J. Ralph Lichtenfels of the Animal Parasitology Institute, USDA, ARS, Beltsville, Maryland, who kindly loaned the type specimens of *P. maomao*. Dr. Kiyoshi Yamazato, Sesoko Marine Science Center and the Ministry of Education, Science and Culture of Japan supported the research of EHW and LBW for 1 year (1985-1986).

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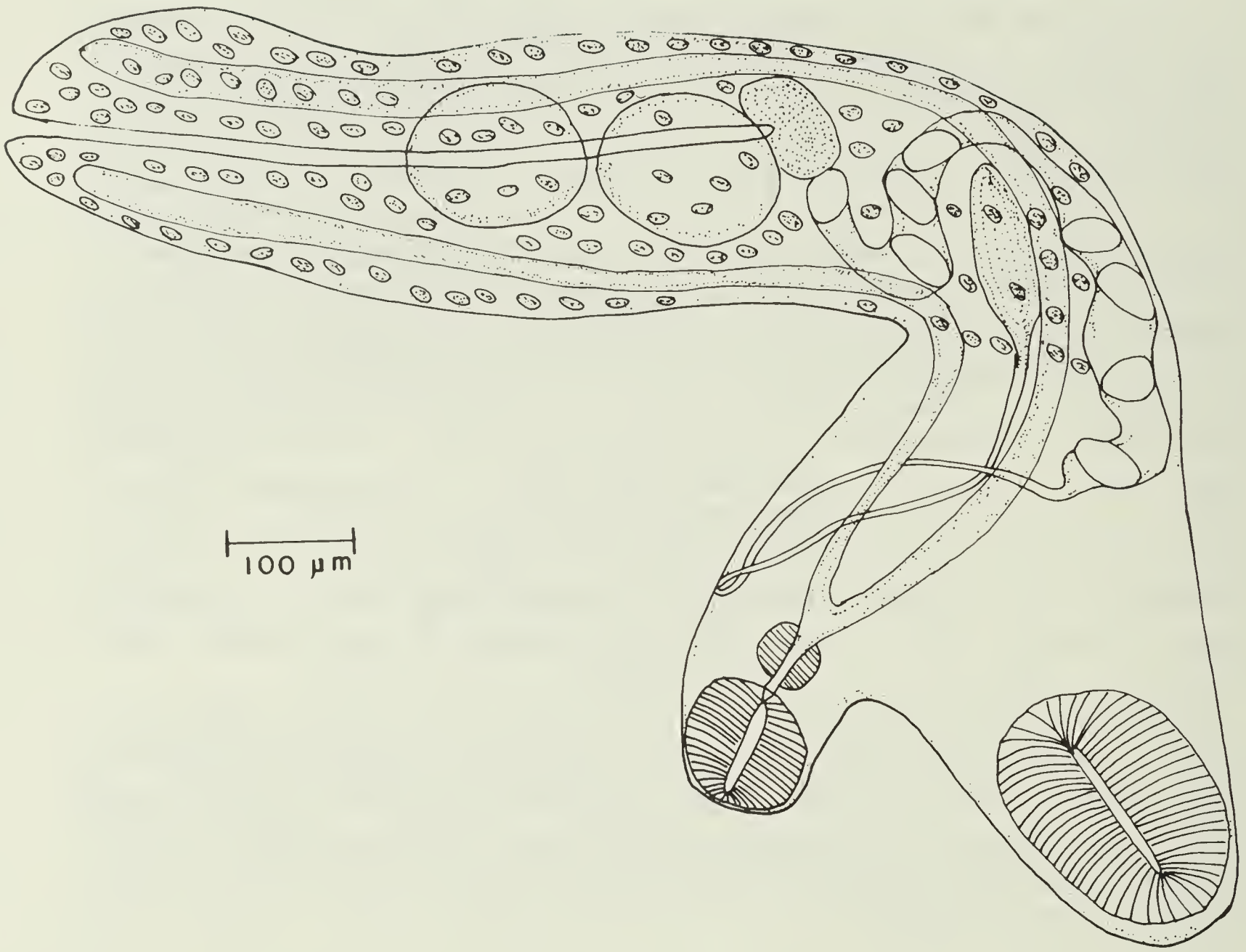

Figure 1. *Pseudopecoelus sesokoensis*, ventral view of holotype, from *Plectorhynchus pictus*.

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REPRODUCTIVE PERFORMANCE OF WHITE-TAILED DEER (ODOCOILEUS VIRGINIANUS) IN WEST-CENTRAL ILLINOIS

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ABSTRACT

Forty-four female white-tailed deer (*Odocoileus virginianus*) were collected as road-kills in west-central Illinois between 1 January and 31 July of 1980, 1981, and 1982. Reproductive tracts of the sample fawn, yearling, and adults were examined for corpora lutea and embryos or fetuses. Data indicated breeding began in late September and continued until early January with three peaks occurring at approximately four-week intervals. Adult does bred earlier than both yearlings and fawns. All adult and yearling does collected had successfully bred and usually carried twins; eighty-five percent of fawns were pregnant and usually carried a single embryo. Differences in counts of corpora lutea and embryos or fetuses suggested an overall failed pregnancy rate of 9 percent. The large percentage of breeding fawns, coupled with a gross natality of 52.3% per year, indicates good range and nutrient conditions are available to the white-tailed deer herd of west-central Illinois.

INTRODUCTION

Gross natality is an estimation of the maximum number of offspring a given population can produce per unit of time (Harder, 1980). Since this value does not consider postnatal mortality factors, it represents a baseline number to assess the effects of diet (Verme, 1969), predation (Bartush and Lewis, 1981), disease (Woolf and Harder, 1979), and management techniques (DelGiudice et al., 1986) on recruitment into a population. Determining gross natality is therefore useful in estimating population size and growth and is a necessary tool for population management (Harder, 1980) and modelling (Stocker, 1983).

Gross natality of white-tailed deer (*Odocoileus virginianus*) herds is often based upon ovulation rates determined from doe reproductive tracts which become readily available during autumn hunting seasons (Nixon, 1971; Harder, 1980). A valid assessment of gross natality from these tracts is often difficult because (1) does are sometimes harvested prior to ovulation, (2) corpora lutea, if present, may be either corpora lutea of estrus or very early corpora lutea of pregnancy (Harder and Moorhead, 1980), and (3) ovulation rates do not necessarily reflect implantation rates (Roseberry and Klimstra, 1970).

Counts of corpora luteal scars (corpora albicantia) from the prior breeding season have also been used to estimate gross natality from autumn reproductive tracts (Adams, 1960; Teer et al., 1965). These counts, too, can be misleading since remnants can be missed during examination of ovarian sections (Harder, 1980), and a 1:1 relationship of corpora albicantia to embryos does not always exist (Teer et al., 1965; Mansell, 1971).

The objectives of this study were to characterize the reproductive performance of fawn, yearling, and adult doe white-tailed deer in west-central Illinois in terms of breeding season and rates of conception, failed pregnancy, and fecundity; and second, to estimate gross natality of the west-central Illinois herd. Data used were from does killed by collisions with motor vehicles from January through July when gestation had sufficiently advanced to identify corpora lutea and count implanted embryos and fetuses (Harder, 1980).

METHODS AND MATERIALS

Forty-four does killed by collisions with motor vehicles between 1 January and 31 July of 1980, 1981, and 1982 were collected in Adams, Brown, Fulton, Hancock, Henderson, Pike, McDonough, Mercer, Schuyler, and Warren counties of west-central Illinois. Does were classified as fawn, yearling, or adult by the tooth replacement-tooth wear method (Severinghaus, 1949). Reproductive tracts were removed and uteri examined for embryos or fetuses, which were back-dated to week of conception (Cheatum and Morton, 1946; Armstrong, 1950).

Ovaries were removed, fixed in 10% formalin, sectioned with a razor blade and examined for corpora lutea (Kirkpatrick, 1980). Corpora lutea were measured and those were diameters greater than 4 mm were classified as corpora lutea of pregnancy (CLP); diameters less than 4 mm were classified corpora lutea of estrus (CLE) (Teer et al., 1965). Twenty randomly-selected ovaries were sectioned using standard histological procedures then stained with eosin and hematoxylin to verify macroscopic identification of structures.

RESULTS AND DISCUSSION

Dates of Conception

Thirty does yielded embryos or fetuses which could be back-dated to week of conception (Fig. 1). It was evident that breeding began in mid-September and continued until early January, indicating a fawning period from late April to late July. Three peaks in breeding activity occurred at approximately four-week intervals with the largest number of conceptions occurring in mid-November (Fig. 1).

Other studies of production in the white-tailed deer have indicated recurrence of estrus cycles every 21 to 28 days are possible throughout the breeding season if a doe is not successfully bred (Cheatum and Morton, 1946; Verme, 1961; Plotka et al., 1977; Plotka et al., 1980). Also, adult does generally enter estrus 28 days prior to yearling and fawn does (Cheatum and Morton, 1946). Consistent with these studies the first peak in breeding activity of the west-central Illinois herd was made up of only adult does (Fig. 1). The second peak approximately four weeks later contained does of all three age groups which probably represented adults re-entering estrus and yearlings and fawns coming into estrus for the first time. The third breeding peak in December may represent the third adult estrus and second estrus for fawns and yearlings (Fig. 1).

The mid-November conception peak is similar to that reported for northern Ohio (Nixon, 1971), western Iowa (Haugen, 1975), and Pennsylvania (Woolf and Harder, 1979), but earlier than for southern Illinois (Roseberry and Klimstra, 1970) and southern Ohio (Nixon, 1971). This variation with respect to latitude, first reported by Cheatum and Morton (1946), has been attributed to thermal or photoperiodic stimulation as well as variations in herd diet and physical condition (Verme and Ozoga, 1987). Conception peak for the west-central Illinois herd is only reported here incidentally and a controlling mechanism is not suggested.

Conception, Failed Pregnancy, and Fecundity Rates

Presence of CLP was assumed to indicate successful conception. Of 44 sets of ovaries, 41 contained at least one CLP, resulting in an overall conception rate of 92 percent (Table 1). Seventeen of 20 fawns (85 percent) yielded CLPs; CLPs were present in all yearling and adult does indicating a 100 percent conception rate (Table 1).

The percent of CLP present without embryo implantation was used as an indicator of the failed pregnancy rate, with probable causes being spontaneous abortion or embryo resorption. A total of 55 CLP were counted from 30 does which carried 50 embryos or fetuses (Table 1). The overall failed pregnancy rate was 9% and appeared to be relatively constant for all three age groups (Table 1).

The fecundity rate was determined by counting the number of embryos or fetuses per total does sampled (Table 1). In most cases, yearling and adult does carried twins while pregnant fawns had a single embryo or fetus. Exceptions were triplets in one adult and one yearling, twins carried by one fawn, and one adult with a single embryo. The overall fecundity rate of the west-central Illinois herd was calculated to be 1.22 offspring per doe (Table 1).

Gross Natality

It is essential to characterize the overall percentage and age distribution of does within the herd to determine gross natality (Harder, 1980). Cumulative harvest data

(Illinois Department of Conservation, 1980-1985) for the ten-county study area prior to "antler-only" hunting gives a reasonable estimation of the sex and age distribution since hunter selectivity biases are diminished by a short hunting season (Nixon, 1971) and large sample size (Harder, 1980). Harvest records indicate does make up 42.6% of the population with percentages of fawn, yearling and adult does being 12.4%, 16.5%, and 22.4%, respectively (Table 2). By applying the age-specific fecundity rates (Table 1) to the doe population percentages for each age group, gross natality of the west-central Illinois deer herd was estimated to be 52.3% (Table 2).

Age-specific fecundity rates and gross natality of the west-central Illinois herd are high in relation to all white-tailed deer of North America, but comparable to other herds from agricultural areas of similar latitude (for regional comparisons see Harder, 1980; Stoll and Parker, 1986). The preponderence of breeding fawn does and similar fecundity rates of yearlings to adults are indicative of good range and nutrient conditions available to the west-central Illinois herd (Woolf and Harder, 1979; Gladfelter, 1980; Severinghaus and Moen, 1983).

It is important to stress that these rates represent gross natality, or maximum reproductive potential, of the white-tailed deer herd of west-central Illinois. Actual or net natality cannot accurately be expressed until factors of postnatal mortality, often highly significant (Bartush and Lewis, 1981), have also been characterized for the herd (Woolf and Harder, 1979; Harder, 1980).

ACKNOWLEDGMENTS

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Table 1. Numbers of does collected, CLP and embryos or fetuses counted, and subsequent rates of conception, pregnancy failure, and fecundity for the west-central Illinois deer herd.

Age	Does Collected	Does Pregnant	Conception Rate	Does with Embryos/ Fetuses	Number of Embryos/ Fetuses	Number of CLP	Pregnancy Failure Rate	Fecundity Rate
Fawn	20	17	0.85	11	13	14	0.07	0.76
Yearling	7	7	1.00	5	10	11	0.09	1.43
Adult	17	17	1.00	14	27	30	0.10	1.59
Total	44	41	0.93	30	50	55	0.09	1.22

Table 2. Determination of gross natality for the west-central Illinois deer herd. Percentages for each age group and sex are based on the cumulative deer harvest from 1981 to 1985 for the ten-county study area (n = 32,324).

Age Group	*Males* No.	%	*Females* No.	%	Fecundity	Gross Natality %
Fawn	7319	22.6	5282	16.3	0.76	12.4
Yearling	6424	19.9	3729	11.5	1.43	16.5
Adult	4818	14.9	4752	14.7	1.59	22.4
					Total Annual Gross Natality:	52.3

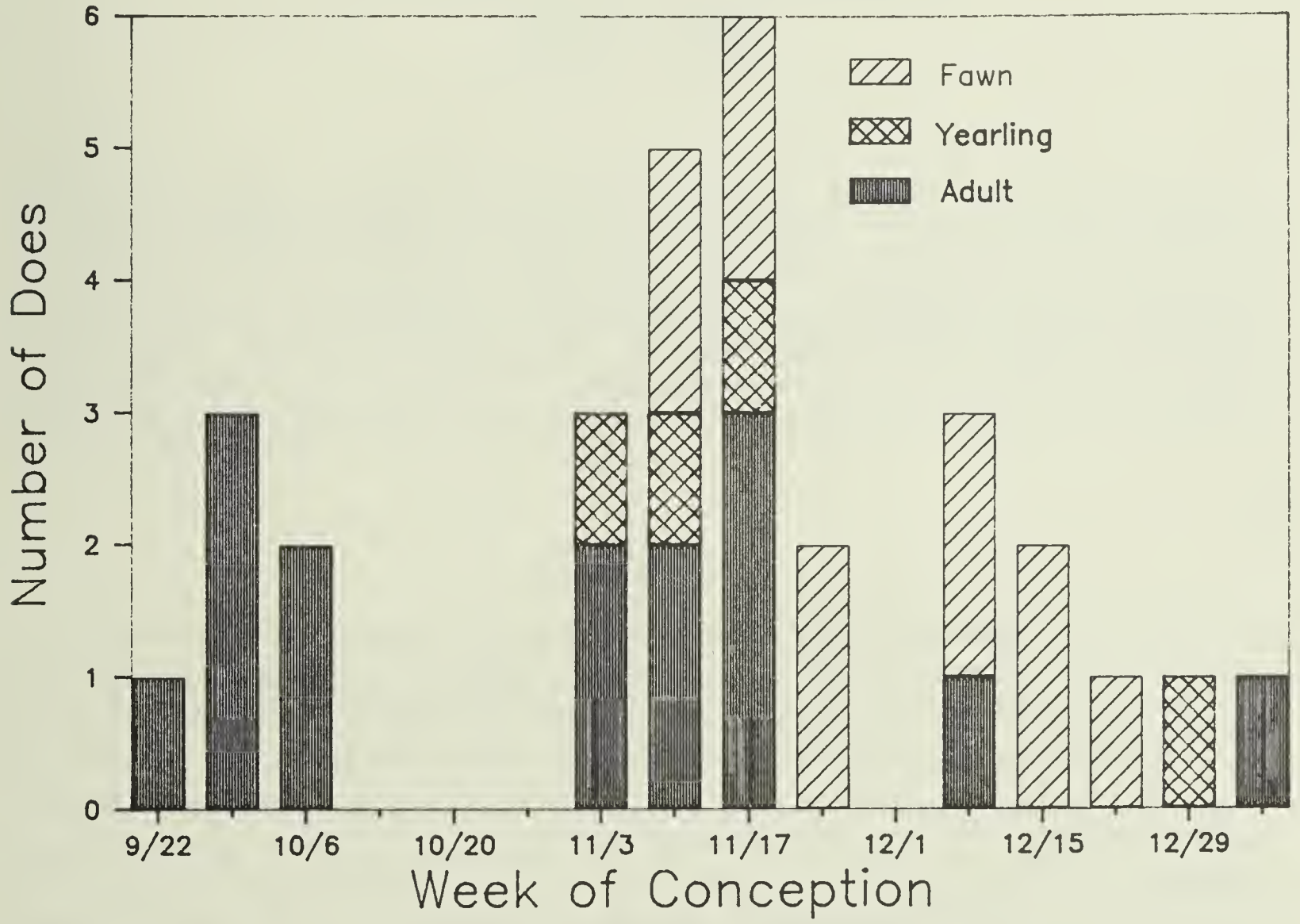

Fig. 1. Calculated weeks of conception for 30 fawn, yearling, and adult does collected in west-central Illinois.

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SEVEN YEAR STUDY OF THE EFFECTS OF PHOTOPERIODS ON THE CIRCANNUAL LOCOMOTOR RHYTHM OF THE GERBIL

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The locomotor activity of groups of 6 male Mongolian gerbils was maintained under four photoperiods, LL, 12L:12D, 18L:6D and 6L:18D. The consecutive experiments lasted from 18 to 30 months with different animals used for each study. The light intensity was 2.2 lux; ambient chamber temperature was 20°± 2°C with no seasonal correlation. Maintenance was kept at a minimum, and food/water were provided *ad libitum*. The composite curves for each experiment had High(s) statistically significant from the Low(s) ($P << 0.001$, Student's t test). The frequencies for each circannual activity rhythm varied with the different photoperiods. Thus, the light/dark cycle acts as a Zeitgeber for the circannual rhythm of the gerbil. Circannual rhythms are known to exist in humans with the LD cycle acting as a potential Zeitgeber, also.

ABSTRACT

The animal and plant kingdoms have various physiological and behavioral traits that increase the survivability of the organism. One such trait is the circannual or seasonal rhythm. The geophysical correlate of the seasonal rhythm is based upon the rotation of the earth around the sun lasting approximately 365 days or 12 months. Repetitive events recurring within a period of 12 months include migration, flowering, moulting, growth, hibernation, fattening, etc. Circannual rhythms are endogenous cycles that repeat at intervals approximating one year under the constant environmental conditions of the laboratory. Such rhythms appear to be under the control of a biological clock, whose mechanism is quite mysterious to present researchers. Even the name has changed over the past decades, from "circennial" (Farner, 1970) to "circannian" (Pengelley, 1967) to the present term "circannual".

Recently there has been an increase in the number of published, scientific papers on these long-term or ultradian rhythms. Circannual rhythms persisting

under seasonally consistent environmental conditions of the laboratory have been observed in a variety of animals. Bats, for example, have circannual rhythms in body weight (Beasley et al., 1984). Ground squirrels also show similar rhythms in activity onset and termination (Lee et al., 1986), blood concentrations of luteinizing and testosterone hormones (Barnes, 1986), body temperature (Hengst and Wiebers, 1984), and body weight (Melnyk, 1983). Matsubayashi and Enomoto (1983) reported circannual, testosterone rhythms in primates. A cnidarian is known to have a circannual rhythm in growth (Brock, 1975). The antler replacement cycle in deer is stated to have a period length approximating one year (Goss, 1984). Natalini (1978, 1982) described circannual activity rhythms of the Mongolian gerbil under continuous dim illumination (LL) and a long-day photoperiod (18L:6D).

These cycles of activity occur spontaneously and may persist under experimentally constant environmental conditions. For activity rhythms timed by a circadian (24-hour) clock, either under natural or laboratory conditions, it is known that the photoperiod is the strongest Zeitgeber or synchronizer (Pittendrigh, 1981). Little is known about the Zeitgeber for circannual clocks. The present studies were conducted to determine and to compare the circannual patterns of gerbil locomotor activity held under various but consistent photoperiods. Therefore, the effects of a lighting regime similar to a daily photoperiod found in summer (18L:6D), the effects of a transitional lighting cycle (12L:12D), and the effects of a lighting regime imitating winter conditions (6L:18D) upon the activity rhythm of the gerbil were studied. Experimental activity cycles were compared to the cycles of animals housed under continuous dim illumination (LL). Results of some of these investigations were reported previously (Natalini, 1978; Natalini, 1982).

Since any consistent laboratory photoperiod would allow the expression of the activity profile of the corresponding circannual period, the existence of different activity patterns indicate that the light/dark cycle is an entraining agent. Circannual rhythms provide the organism with the adaptive advantage of anticipating seasonal situations and of helping to synchronize various complex physiological and behavioral traits. When the light/dark cycle not only entrains a rhythm but also induces an event such as found in various photoperiodic phenomena, such phenomena may also have annual periodicities. It is now known that even man possesses yearly cycles. Further considerations and the significance of such rhythms are deferred to the Discussion portion of this report.

MATERIALS AND METHODS

This report summarizes the results of past experiments and presents new data on two of four research projects. The photoperiod for each experiment changed. Experiment I, lasting from October, 1975, to March, 1977, was held under LL. Experiment II, lasting from September, 1977, to March, 1979, maintained a 12L:12D photoperiod. Project III, lasting from September, 1980, to March, 1982, had the long-day schedule of 18L:6D; and the final experiment with the short-day of 6L:18D started in October, 1983, and ended in March, 1986.

In each study six, 6-week-old male Mongolian gerbils, *Meriones ungiculatus*, served as the experimental animals. It should be emphasized that separate gerbils were used for each experiment. Lights on for the rectangular photoperiods were at 06:00 hr., Central Standard Time; lights off occurred at the appropriate time. The

intensity of the incandescent white light at the center of the cage was 2.2 lux. Feedings consisted of Purina rat pellets and tap water *ad libitum*. The ambient chamber temperature was continuously monitored at 20° ± 2°C and was theromostatically controlled. Humidity was not controlled. Since there was no seasonal correlation with the environmental temperature change, since temperature is a poor entraining agent for homeotherms, and since biological clocks possess temperature compensation so that the clock runs independently of the temperature, it is unlikely that there were any temperature influences (also see: Tokura and Aschoff, 1983; Gibbs, 1983).

For the first two studies, the experimental animals were housed in tipping cage actographs, while the last two were conducted in running wheels. The tipping cage actographs pivot on a knife blade in such a way that any movement causes a deflection of microswitches (Boyer and Truchan, 1969). The Wahmann running-wheel cages have a wire mesh (9.0 mm) revolving wheel (diameter 35 cm) with access to a stationary living compartment (25.5L × 15.5W × 12.5H cm). Cleaning of the trays under the cages occurred once a month, and all maintenance was kept to a minimum. Data from the two kinds of cages might differ in amplitude, but not in period length (Natalini, unpublished).

Locomotor activity was recorded separately for each gerbil on an Esterline Angus event recorder in continuous operation with a chart speed of 45.5 cm/24 hr. Each microswitch activation produced a single pen deflection. Quantification of the data and statistical analysis have been described (Natalini, 1978). Briefly, each gerbil-hour of activity is assigned a value of 0 to 10 (0% to 100%) based on the amount of hourly activity. A Mean ± Standard Error of the Mean was calculated for the High (Peak) and Low (Trough) months of activity. Differences between the Peak and Trough were determined by a student's t test. Thus, each animal can act as its own "control" by comparing the High with the Low point. Results from the LL experiment act as a "control" also. The location of the experimental animals enabled olfactory and visual cues from each other, but I noted no mutual entrainment as indicated by the individual activity patterns.

RESULTS

Figure 1 illustrates the composite curves, each representing the mean, monthly activity of six gerbils under the various photoperiods. Under continuous dim illumination (LL), there is a High (Peak) in April and a Low (Trough) in February (Natalini, 1978). Under the equal light and dark photoregime (12L:12D), there is a High in October of year 1 and Highs in May and November of year 2. The Lows are located in December of year 1 and January of year 2. The six gerbils producing the composite curve of the long-day photoperiod (18L:6D) have Highs in November (year 1) and April (year 2) with a Low in January, beginning of year 3 (Natalini, 1982). Conditions of the short-day photoperiod (6L:18D) result in a Peak in May and a Trough 14 months later.

Figure 2 is another way by which the Highs and Lows may be demonstrated. Indicated in the figure are the Peaks and Valleys only for the composite curves. The error bars are plus/minus one standard error of the mean. Results from a student's t test indicated that the selected points are statistically significant with a P value much less than 0.001. Within the individual experiments, at least four of the six

gerbils had graphs with Peaks/Troughs significant to the above level. The composite curves of Figures 1 and 2 still represent all 6 gerbils, no data was eliminated. Figure 2 also indicates the genetic individuality between animals by noting the differences in amplitude between the selected points.

A common analytical method of students of biological rhythms is to allow each animal to act as its own "control" so that within the longitudinal study one part (High) of a curve is compared to another part (Low). This is also true for the composite curves. LL can be considered a "control" since it lacks a photoperiod, but the graph would be expected to change in appearance if the light intensity were increased or continuous dark (DD) were used. In addition, to demonstrate a true endogenous, circannual period, one should have multiple Peaks or Valleys as noted in the 12L:12D light regime. At least two animals within each experiment indicated multiple Peaks (or Valleys); thus, I believe these results indicate true circannual periods.

DISCUSSION

With my series of experiments, I tested the hypothesis that the LD cycle could affect the appearance of the circannual activity period of the Mongolian gerbil. The data from the LL experiment indicates that the gerbils possess a circannual rhythm of locomotor activity. Figure 1 demonstrates the changes in the frequency of the activity rhythm under the different photoperiods, thus indicating that the endogenous circannual rhythm of activity is entrained by the photoperiodic Zeitgeber. While performing the analysis of the data, I clearly noted the daily (circadian) activity was entrained by the LD cycle, but the Highs and Lows of the seasonal rhythm were not entrained instead, the rhythms freeran with a period shorter or longer than 12 months.

There is a paucity of data demonstrating that the photoperiod can entrain the circannual period. Blake (1963) reported that the LD cycle can entrain the rhythm of diapause in an insect. Reproductive readiness in birds (Gwinner, 1977) and antler development in deer (Goss, 1977) are synchronized by the LD cycle. To consider the results valid, the experimenter should study the effects of the various photoperiods over many months and should not observe animals removed from the laboratory or natural environment to study for a few months. The effects of the previous lighting regime could have lasting influences. The constant conditions of food/water availability, temperature, social cues, and the photoperiod will manifest the circannual rhythm (Joy and Mrosovsky, 1985).

The LD cycle is pivotal for the process of photoperiodism where the length of the light (or dark), upon reaching a critical duration institutes some physiological or behavioral change in the organism. Thus, many photoperiodic phenomena such as moulting, fattening, reproductive readiness, migration, etc., have annual cycles. Nevertheless, the above annual rhythms need not be timed by a circannual bioclock. Models for the photoperiodic phenomena are based upon "external" or "internal" coincidence. (For a recent review see: Meier and Russo, 1984.) In any case models are simply "formulas" used by the students of biorhythms to organize their thoughts and research. Neither of the above two models has been proven or disproven.

Activity rhythms are not considered to be photoperiodic. Their circannual nature becomes apparent under the constant condition of LL, DD or LD, but LD conditions may not be totally information free (Chandola et al., 1983). It might be possible that the gerbil possesses some other physiologic parameter not observed that is photoperiodic and could provide timing cues to the locomotor rhythm. Thus, their circannual nature may not be due to an endogenous, self-sustained pacemaker.

Quantitatively the length of the circannual period should vary around 12 months (Gwinner, 1981). The ones that I have described vary a great deal more or less than 12 months since for some only half-cycles are indicated. These cycles are indistinguishable from the circannual rhythms. It is quite possible that there is a wide variety of interspecific variation of circannual periodicities. The pacemaker generating such periodicities would require environmental cues such as the LD cycle to synchronize the physiological rhythms with the environmental ones. It is not known to me why such a large deviation would exist between the environmental cues and the bioclock.

There are additional models which attempt to explain circannual rhythms. The organism could somehow count the circadian cycles (Meier and Russo, 1984). Joy and Mrosovsdky (1985) proposed an evolutionary sequences of stages which added together produce yearly cycles. The stages might have consisted of periods of fattening, reproductive readiness, reproduction, quiescence, etc., each stage lasting a few months, but when added sequentially a year is obtained. Another commonly discussed model is frequency demultiplication. The interaction of two circadian rhythms could be transduced into the longer period of a year (Dark et al., 1985). My future studies will relate to a search for an annual sensitivity to light, i.e., an annual phase response curve to light. A annual phase response curve must exist so that the LD cycle can entrain the yearly cycle. (For the classical study in this area see: DeCoursey, 1960).

Recently Czeisler et al. (1986) reported that light can act as a Zeitgeber for human circadian rhythms, also indicating the presence of a phase response curve in us. Light may be used to phase advance or delay human rhythms without the intervention of a chemical agent. Obviously, it would be impossible to maintain people under unvarying conditions for many months, but we are known to have seasonal rhythms in body temperature and length of sleep when maintained under constant conditions for short periods of time during the various seasons (Wirz-Justice et al., 1984). It is also obvious that annual clocks are required to synchronize the many reproductive and behavioral processes in animals. In the study of annual clocks, we still are researching at very preliminary quantitative levels.

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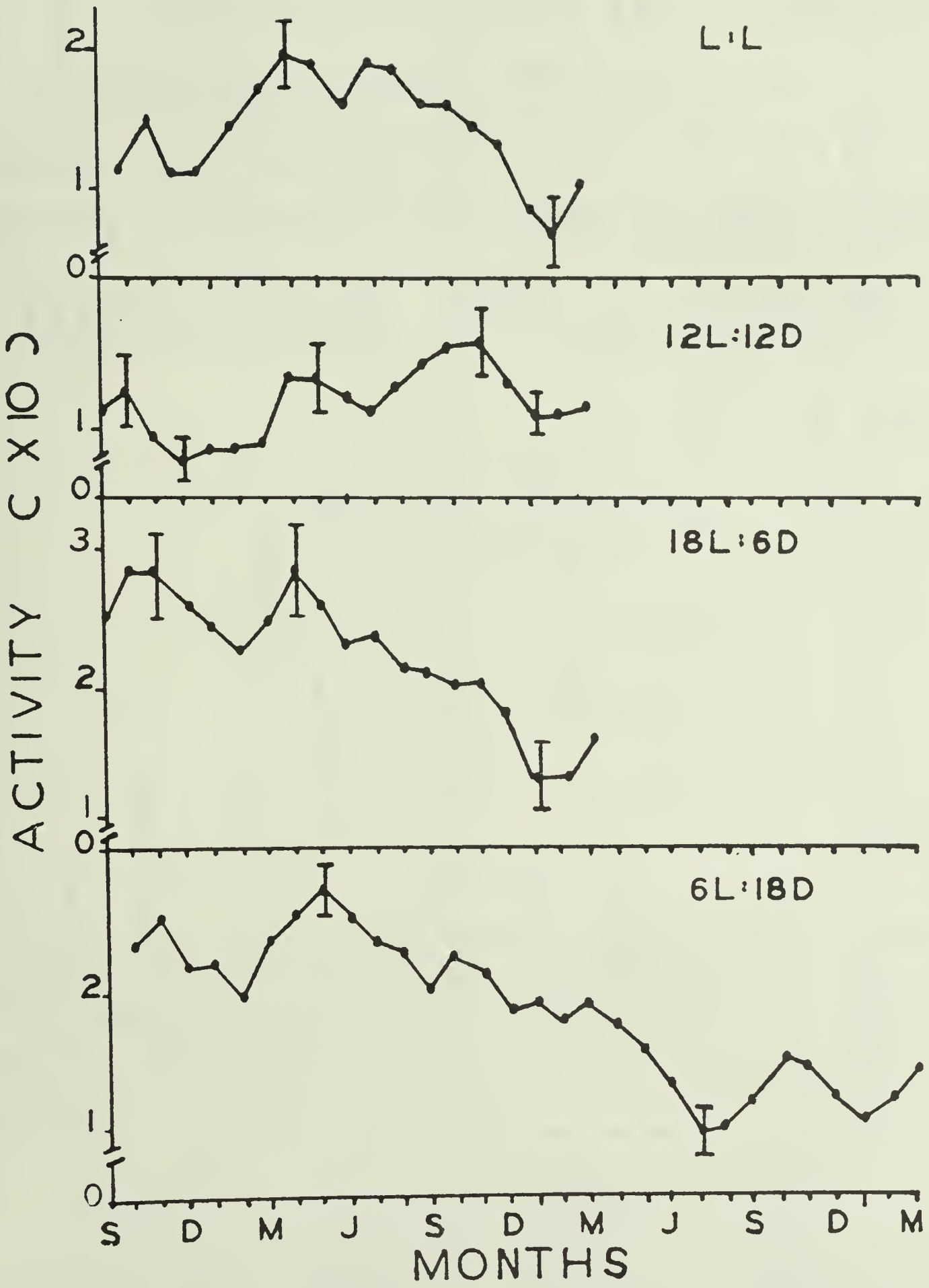

Figure 1. Summated curves for six gerbils under each of four experimental conditions: LL (Natalini, 1978); 12L:12D; 18L:6D (Natalini, 1982); and 6L:18D. Each value is the monthly mean ± SEM. Note the discontinuities in the ordinate axis.

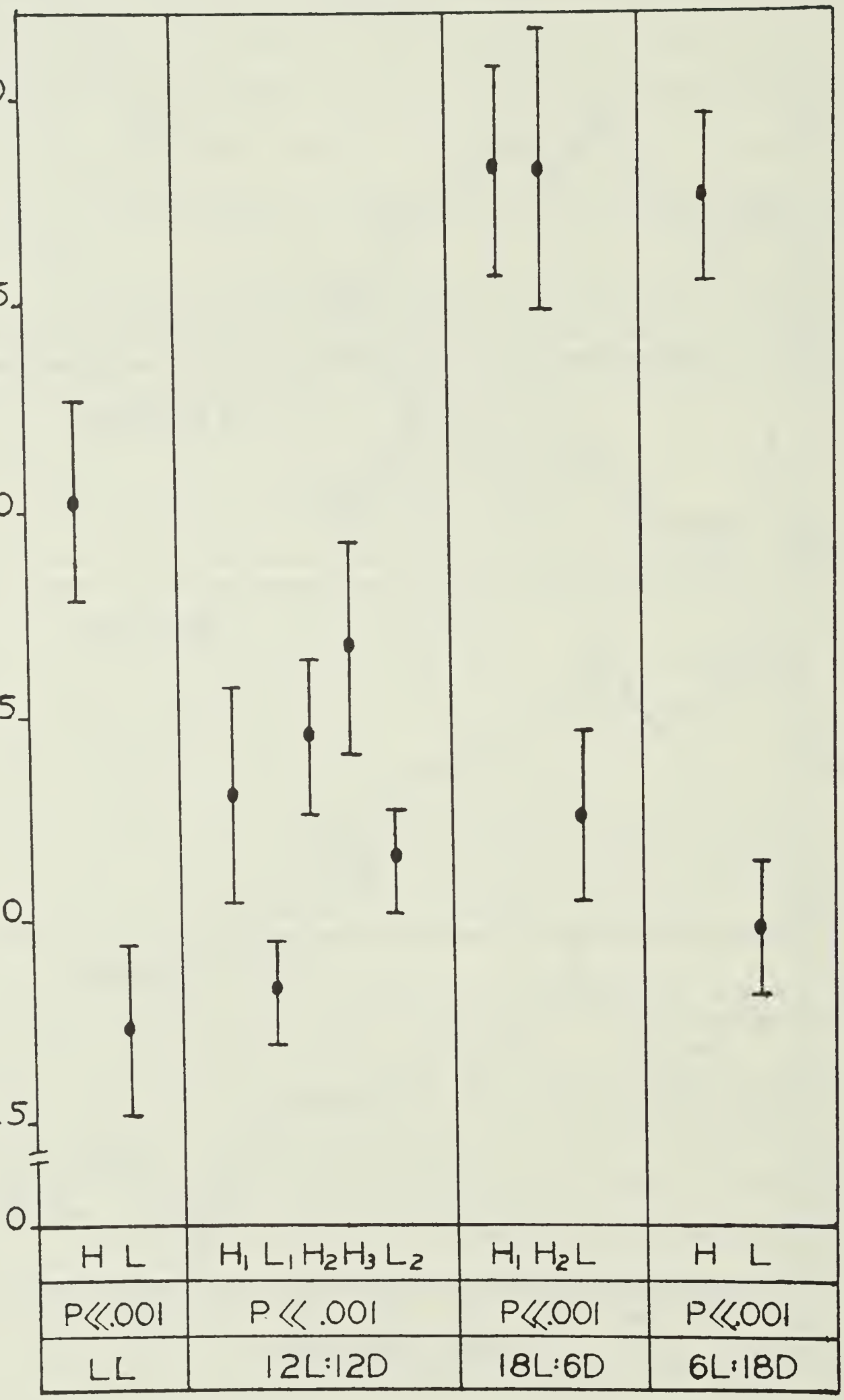

Figure 2. ± One standard error of the mean for the Highs and Lows of Figure 1. Each value represents 6 gerbils. Probability was calculated by a student's t test indicating a level of significance much less than 0.001. Notice discontinuity in the ordinate axis.

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OBSERVATIONS ON THE REPRODUCTIVE BEHAVIOR AND EGGS OF FOUR SPECIES OF DARTERS, WITH COMMENTS ON ETHEOSTOMA TIPPECANOE AND E. CAMURUM

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ABSTRACT

Observations on *Percina phoxocephala, Etheostoma sagitta, E. jordani,* and *E. punctulatum,* all of which are egg-buriers, bring to 73 the number of darters (and to 81 the number of species of percids) for which descriptions of spawning behaviors have been published. The egg-burying *E. tippecanoe* and *E. camurum* have spawning characteristics that may be preadaptive for the evolution of the egg-clumping behavior found in closely related species.

INTRODUCTION

The observations that follow were made on the reproductive behaviors of darters in aquaria. In each instance, choices were made available to the darters so that they could bury, attach, clump, or cluster eggs, as has been observed in other species (Page 1985).

Previously reported observations on the behaviors of 76 percids, including 68 darters, were summarized by Page (1985). Information on *Etheostoma acuticeps*

published by Simon et al. (1987) and the following observations on the slenderhead darter (*Percina phoxocephala*), arrow darter (*E. sagitta*), greenbreast darter (*E. jordani*), and stippled darter (*E. punctulatum*), bring to 81 the number of percids (and to 73 the number of species of darters) for which descriptions of spawning behaviors have been published.

PERCINA (SWAINIA) PHOXOCEPHALA

Two females and 13 males were collected in the Embarras River, Cumberland County, Illinois, on 1 June 1985 and transferred to a 200 gallon aquarium with a power filter. The filter created a slow clockwise current. Substrates in the aquarium included areas of fine gravel, sand, and mixed sand and gravel. Included as additional potential spawning sites were a large flat rock elevated at one end to create beneath it the kind of cavity used by egg-clumpers and egg-clusterers (Page 1985), other large rocks, aquatic plants (in the center of the aquarium), and a yarn mop near the filter on one side of the aquarium.

Males developed black markings and a bright red-orange band in the first dorsal fin. Females developed swollen abdomens and relatively long genital papillae. Spawning was observed on 8 May, 23 June, and 29 June 1986. During spawning, the female buried her papilla about 1 cm beneath the surface of the substrate. The male mounted the female, forming an "S," with his head on one side and his tail on the other side of the female, as has been described for other darters (e.g., Winn 1958). Each spawning act lasted about four seconds. Each time spawning was observed, the eggs were buried in mixed gravel and sand areas behind (relative to the current) large rocks. Eggs were also found (but spawning was not observed) on 22 May and 19 June (aquarium temperatures ranged from 18-22°C). Eggs (N = 8) were 1.7-1.8 (mean = 1.7) mm in diameter, transparent, spherical, demersal, and nonadhesive; they had moderate perivitelline spaces, pale yellow yolks, and unpigmented chorions. At 22°C eggs hatched in 120-124 hrs.

Earlier ecological studies on *P. phoxocephala* identified the spawning period and habitat but did not include observations on spawning behavior. Thomas (1970) and Page and Smith (1971) found that spawning in central Illinois occurred in June and possibly July in swift-flowing water 15-60 cm deep over gravel. Males moved into this habitat in large numbers before the arrival of females and were thought to establish territories. In our aquarium, males schooled until near spawning time and then dispersed more evenly about the aquarium, a behavior that suggested the establishment of territories.

Observations on spawning in *P. phoxocephala* increase to eight the number of species, and to six the number of subgenera, of *Percina* for which information has been reported. All have been found to be egg-buriers. Egg-burying is the primitive behavior among darters (Page 1985), and we predict that all species of this primitive genus of darters will be found to be egg-buriers.

ETHEOSTOMA (LITOCARA) SAGITTA

One male and two females collected in Stinking Creek, Campbell County, Tennessee, on 13 June 1985 were transferred to a 60 gallon aquarium. One-half of the aquarium bottom was covered with fine gravel, the other was left bare to simulate bedrock. A large rock was placed in one corner of the bare half of the

aquarium and another was partially buried in the gravel. The male was in bright breeding coloration, the females were comparatively dull with some swelling of their abdomens.

On 9 March 1986 (11:30 A.M.; 15.5°C), the male was observed courting the large female and chasing away the small female. Courting consisted of lateral displays to the female with the median fins spread. Eventually the male approached the female and nudged her in the abdomen with his snout. The female inserted her snout into the gravel and seemed to flip gravel forward as she wiggled into the gravel, buried her abdomen, and moved forward slowly with the male positioned above her. The male's body formed an "S," with his head on one side of the female and his tail on the other. Each spawning act lasted about seven seconds, followed by a 15-second break, and then another spawning act. The same pair spawned again on 10 March 1986 (10:30 A.M.; 15.5°C). All spawning occurred in deep gravel. Eggs (N = 5) were 1.8-1.9 (mean = 1.8) mm in diameter, transparent, spherical, demersal, and nonadhesive; they had large perivitelline spaces and uncolored yolks and chorions. At 15.5-16°C eggs hatched in 240-253 hrs.

Etheostoma sagitta is closely related to *E. nianguae*, the two being the only members of the subgenus *Litocara* (Page 1981). Spawning in *E. nianguae* was described by Pflieger (1978). Both species are egg-buriers.

ETHEOSTOMA (NOTHONOTUS) JORDANI

Three males and three females were collected in the Conasauga River, Bradley County, Tennessee, 14 June 1985 and transferred to a 40 gallon aquarium. The aquarium bottom was covered with fine gravel. A flat piece of slate, elevated at one end, and a half flowerpot were provided as potential spawning cavities. The slate and the flowerpot were about 15 cm apart.

Several unobserved spawnings occurred, and 28 eggs were found over a five-month period (29 April to 4 August 1986; 18-21°C). These eggs had been buried in deep gravel away from the cavities, and no more than three eggs were found in a single location. Eggs (N = 19) were 1.7-2.0 (mean = 1.9) mm in diameter, transparent, spherical, demersal, nonadhesive and unclumped; they had narrow perivitelline spaces, pale yellow to uncolored yolks, and unpigmented chorions.

Some species of *Nothonotus* (*E. juliae*, *E. rufilineatum*, *E. camurum*, *E. bellum*, *E. tippecanoe*, and *E. acuticeps*) bury eggs, and some (*E. maculatum*, *E. microlepidum*, *E. aquali*, and *E. sanguifluum*) clump them under large stones (Page 1985; Simon et al. 1987). In the latter group of species, males guard the eggs. Phylogenetic relationships within *Nothonotus* are unclear except for the close relationship among species in the egg-clumping (i.e., *E. maculatum*) group (Page 1985). *E. jordani* clearly lies outside the *E. maculatum* group as indicated both by its morphology (Zorach 1969) and by its egg-burying behavior.

ETHEOSTOMA (NOTHONOTUS) TIPPECANOE AND E. (N) CAMURUM

We also observed *E. tippecanoe* and *E. camurum*, two species of *Nothonotus* reported in the literature to be egg-buriers (Trautman 1957; Mount 1959; Warren et al. 1986). Our observations agreed with those of earlier reports, but offered additional insight into how egg-clumping in the *E. maculatum* group of *Nothonotus* may have evolved.

Two male and two female *E. tippecanoe* collected in Tippecanoe River, Pulaski County, Indiana, 27 July 1985 were placed in a 20 gallon aquarium with a substrate of fine gravel and several fist-sized quasi-rectangular rocks. The larger male, which became brilliant orange on the side, dark orange above, and had a dark blue breast used his caudal and anal fins to excavate a cavity beneath one of the large rocks. Although no way in and out of the cavity was apparent, we later discovered upon lifting the rock that a male and two females were in the cavity. Subsequent observations revealed that females buried themselves completely in the gravel during egg-laying, and that the male remained above the gravel directly over them.

Similar behavior was observed in *E. camurum*. Two males and three females (from Tippecanoe River, Pulaski County, Indiana, 27 July 1985) were placed in a 30 gallon aquarium with a large flat rock elevated at one end. Half of the aquarium bottom was uncovered, and fine gravel covered the other half. A disc-shaped sponge filter was located in one corner. Several spawnings were observed in April and May 1986. Some spawnings occurred over the gravel in the open; at other times, the female wedged her body between the filter and the side of the aquarium. The larger male mounted the female and kept his body parallel to hers. The female remained more or less stationary during the spawning act, producing a partially buried, grape-like mass of eggs similar to that described for *E. camurum* by Mount (1959). After spawning, the female wiggled forward and lifted her tail, appearing to expose her genital papilla to the male. The male joined her and spawned again. Each spawning act lasted about 15 seconds, with about 30 seconds between acts, and with the female swimming forward a few cm between each act. As in *E. tippecanoe*, a hidden spawning site (beside the filter) often was chosen.

Earlier observations on spawning in *E. tippecanoe* (Trautman 1957; Warren et al. 1986) did not mention the habit of burying beneath rocks and other objects. However, Warren et al. (1986) made the interesting observation that egg-burying in *Nothonotus* differs fundamentally from that in *Oligocephalus* in that females remain buried and eggs are laid "in small clusters (e.g., *E. tippecanoe*) or in large clumps (e.g., *E. camurum*, Mount 1959)." In *Oligocephalus*, females are much more active and eggs are scattered within the loose substrate. The preferences for burying eggs beneath rocks and laying them in clumps seem preadaptive to the evolution of egg-clumping behavior (Page 1985) in the *E. maculatum* species group of *Nothonotus*.

Eggs of *E. tippecanoe* (N = 7) were 1.3-1.4 (mean = 1.4) mm in diameter, transparent, spherical, demersal, and adhesive; they had narrow perivitelline spaces, amber yolks, and unpigmented chorions. At 22°C eggs hatched in 144-168 hrs. Eggs of *E. camurum* (N = 21) were 1.6-2.2 (mean = 1.8) mm in diameter, transparent, spherical, demersal, and adhesive; they had narrow perivitelline spaces, uncolored yolks, and unpigmented chorions. At 22°C eggs hatched in 168-240 hrs.

ETHEOSTOMA (OZARKA) PUNCTULATUM

Two males and one female from Osage River, Missouri, 11 January 1985, were observed spawning in a 40 gallon aquarium many times between February and late June 1986. The aquarium contained fine gravel and a large rock, elevated at one end

to create a cavity. During spawning, the female swam forward and buried her body about half-way in the gravel. With his head lifted, the male positioned himself beside and parallel to the female. The female spawned with both males, but only with one at a time. Each spawning act lasted about eight seconds. Spawning fish were more active than were those of species of *Nothonotus*, often swimming in and out of the gravel as observed in species of *Oligocephalus*. Temperatures ranged from 18-22°C. Eggs (N = 37) were 2.0-2.4 (mean = 2.1) mm in diameter, transparent, spherical, demersal, and nonadhesive; they had narrow perivitelline spaces, pale yellow yolks, and heavily pigmented chorions. At 22°C, eggs hatched in 121-136 hrs.

Observations have been made previously on three members of the subgenus *Ozarka*. *E. cragini* was observed in an aquarium to bury its eggs in fine gravel (Distler 1972), and *E. boschungi* and *E. trisella* have been observed to attach eggs to vegetation in seepage areas (Boschung 1979; Ryon 1986).

Unfortunately, vegetation was not available in the aquarium in which *E. punctulatum* spawned, and only floating vegetation was available to *E. cragini* (Distler 1972). A preference by these two species for rooted vegetation similar to that used as a spawning site by *E. boschungi* and *E. trisella* cannot be ruled out. The potential for darters to revert to a more primitive spawning behavior was demonstrated by the observations made on *E. nigrum* by Forbes and Richardson (1908). Although *E. nigrum* is an egg-clusterer (Winn 1958; Page 1985), it reverted to the more primitive mode of egg-burying when held in an aquarium without objects on which to cluster eggs.

> "The species [*Etheostoma nigrum*] spawns in spring, from the last of April to the first of June. Females were depositing their eggs in our aquarium at Meredosia, April 28 and 29, 1899. In the act of spawning the male rode on the back of the female, with ventrals astride, and pectorals and ventrals in active vibration as the pair moved about on the bottom. The eggs are emitted at intervals, and from time to time the female raises a cloud of sand by a vigorous beating with the tail, perhaps for the purpose of covering them." (Forbes and Richardson 1908:296-297).

Since species can revert to more primitive behaviors, aquarium-held fishes must be allowed to choose from among all plausible spawning substrates. *E. cragini* and *E. punctulatum* should be listed only provisionally as egg-buriers.

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We extend special thanks to Nancy Garcia, whose abilities to keep and spawn darters in aquaria resulted in the observations reported here. B.M. Burr, R. Coleman, R.J. Goldstein, R. Wallus and the members of the Michiana Aquarium Club assisted us in collecting brood stock. The manuscript was read and improved by N. Garcia, M.L. Warren, Jr., and C.E. Johnston.

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DISCOVERY OF THE WESTERN SAND DARTER, AMMOCRYPTA CLARA, IN THE MISSISSIPPI RIVER BELOW THE CONFLUENCE OF THE MISSOURI RIVER

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ABSTRACT

A recently discovered population of *Ammocrypta clara* from the Mississippi River near Grand Tower, Illinois is reported.

DISCUSSION

Ammocrypta clara is an inhabitant of sandy-bottomed rivers and large streams in the Lake Michigan drainage and the Sabine and Mississippi river systems. The distribution of the western sand darter is described in detail by Williams (1975) and Page (1983). In Illinois, the western sand darter was previously known to occur in the Mississippi River above the mouth of the Missouri River and in the Sugar and Kaskaskia rivers (Smith, 1979). The range of *A. clara* has been dramatically reduced in Illinois and the construction of reservoirs may have eliminated it from the Kaskaskia River (Smith, 1979). Currently, the western sand darter is under consideration for endangered status in Illinois.

Several recent collections from the Mississippi River near the village of Grand Tower in Jackson County, Illinois have revealed a population of *A. clara* and represent a significant range extension for this species in the Mississippi River. The capture of a juvenile specimen (16.9 mm SL) supports the contention that the specimens reported here represent a viable population. The western sand darter

ranges as far south as the Neches and Sabine rivers in eastern Texas (Williams, 1975); however, there are no published records of this species from the Mississippi River below the mouth of the Missouri River.

All specimens were collected over a sand substrate with a 20′ fine mesh bag seine. Specimens were collected along the shoreline of the beach of Devil's Backbone State Park, approximate river mile 80.5, and along the western shoreline of the island at river mile 79. The mouth of the Ohio River is designated as river mile zero by the United States Geological Survey. The following specimens have been deposited in the Ichthyology Collection of the Zoology Department of Southern Illinois University at Carbondale. The standard length in mm of each specimen preserved is in parentheses. *Ammocrypta clara*. IL: Jackson Co., Mississippi River near Grand Tower, SIUC 12322 (29, 35.7) 7 Sep 1985; SIUC 12321 (31, 38.7, 42.7) 20 Sep 1985; SIUC 12379 (30.2, 32.1) 28 Sep 1985; SIUC 12764 (32.7) 26 Oct 1985; SIUC 15487 (16.9) 13 Sep 1987.

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ORGANIC AMENDMENTS COMPARED TO TOPSOIL REPLACEMENT FOR THE RECLAMATION OF PRIME FARMLAND

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ABSTRACT

The incorporation of organic amendments into reconstructed stripmine spoil may provide an alternative to topsoil replacement. This method may offer an extra advantage when the topsoil on the premined land is thin or eroded. The objective of this study was to determine the effects of incorporating various organic amendments in the surface spoil of stripmined prime farmland compared to topsoil replacement on corn (*Zea mays* L.) performance. This research was conducted on severely compacted spoils at Peabody Coal's Will Scarlet Mine near Stonefort, Williamson County, Illinois. Four manure rates (0, 50, 100 and 200 Mg ha^{-1}), a green manure crop (rye cereal, *Secale cereale* L.), and hairy vetch (*Vicia villosa* L.), and a sod crop (tall fescue, *Festuca arundinacea* (Schreb.) were incorporated into strip mine spoil.

All of the organic amendments increased organic matter content of spoil material, however, they only had a slight affect on soil bulk densities at the 0-30 cm depth. Corn leaf tissue analyses indicated that adequate amounts of nutrients were obtained by the corn from the amended spoil. The addition of the organic amendments into the strip mine spoil gave as good or better corn yields than topsoil replacement. Corn production on organically amended spoil offers a possible alternative to topsoil replacement on some strip mine prime farmland.

INTRODUCTION

The federal government enacted The Federal Surface Mining Control and Reclamation Act in 1977. This law sets forth specific guidelines for the reclamation

of prime farmland. The law requires the separation and replacement of A, B, and C soil horizons in the reclamation process. The B and C-horizons may be combined if it can be shown together they are equal to or more favorable for plant growth than the segregated B-horizon.

Horizontal replacement of topsoil is required by the law. Generally, it's purpose is to provide favorable environmental conditions for crop growth by preserving soil organic matter. This provision is appropriate in areas where a thick topsoil layer is present. However, southern Illinois, Indiana, and western Kentucky have characteristically thin-layered A-horizons developed under forest vegetation which are quite low in organic matter. Dense clay pans have resulted from accumulative leaching from the A-horizon to the B-horizon. These clay pans restrict water penetration, drainage, aeration, and root penetration. Also, the pre-mine fields are sometimes sloping and moderately to highly eroded often with little topsoil remaining. A possible alternative to topsoiling may be the incorporation of various organic amendments to improve crop production and reduce reclamation costs. Many coal companies have cattle operations as part of their reclamation program. This offers an inexpensive and readily available source of organic matter. As an alternative, the incorporation of a grass/legume sod or green manure crop could provide a valuable source of organic matter.

Research work conducted by Barnhisel (1977) raised a question regarding the recommendation of topsoiling. The physical and chemical properties found in the available topsoil material may be less desirable than certain geologic materials found in the lower profile. Carter et al. (1973) observed that Illinois spoils contained more available nutrients than the topsoil except for nitrogen, but lacked organic matter. McFee et al. (1981) indicated that additional knowledge is required on mine overburden properties, placement, and plant growth potential. Although topsoil is required by law, the best plant growth medium may be other overburden strata that could be placed near the surface more efficiently and economically. Various combinations of substratum and B-horizon materials as subsurface rooting media were evaluated by McSweeney et al. (1981). Their findings suggest that in southern Illinois selective subsurface blending would produce a better soil than segregation and replacement of the B-horizon from mined soils. Area with problems in the B-horizon can be identified by soil survey interpretation.

One means of adding organic matter to mine spoils is the growing of a grass/legume sod building crop or a green manure crop, thus improving the soil's physical character. Carter et al. (1973) reported that the decomposition of forage residue contributes to organic matter accumulation. Above ground vegetation will improve soil structure thus reducing erosion and increasing infiltration. Johnston et al. (1942) observed that the growth of sod crops improved soil aggregation. Grandt (1978) noted that newly mined land should not be planted to row crops but seeded to a grass/legume mixture first to allow the soil to set properly. During this time, the soil's biological, physical, and chemical aspects will stabilize, thus allowing for the successful future cultivation of row crops.

The beneficial effects of organic matter applications in the form of animal manures have been studied. Hafez (1974) found that beef and dairy cattle manures on mine spoils had decreased the bulk density with each increasing rate of manure and the percentage moisture holding capacity increased proportionately. There was an improvement of soil structure through a higher degree of soil particle

aggregation. Meek et al. (1982) evaluated the long-term effect of manure application rates (0-540 t ha^{-1}) on the various soil chemical and physical properties. Manure increased the soil organic matter 1.0-1.2 percent and about 30 percent of the organic matter which was applied remained five years later. Organic matter was an important factor contributing to increases in water intake rates.

Weathered soils with limiting chemical and physical properties in the subsoil horizon may be improved agronomically by mixing deeper strata with the limiting horizon (Stucky et al., 1986). However, compaction can have an adverse effect on the reconstructed profiles. Compaction destroys soil structure, increases soil strength and the size and the amount of macro — pore space. This pore volume is important in water infiltration and movement through the soil (Chong et al., 1986). McSweeney et al., 1987 reported that the lack of pore space restricts proper root development and proliferation thus restricting growth. Schroeder and Halvorson, 1988 noted that net soil water depletion was less in reclaimed soil profiles than on the undisturbed soil profiles. It was also observed that soil water depletion within the reclaimed soil was affected by topsoil thickness and spoil texture through effects on available water at planting and soil strength effects on root penetration.

The purpose of this study was to evaluate the effects of incorporating organic amendments into a mixture of unconsolidated overburden from surface mined prime farmland compared to topsoil replacement on corn (*Zea mays* L.) performance.

MATERIALS AND METHODS

Research Site

A field study was conducted at Peabody Coal's Will Scarlet Mine near Stonefort, Williamson County, Illinois. The research site, classified as Pit 16, was mined in October, 1977. The rooting media consisted of a mixture of 1.2-1.5 m of loess and 9-15 m of glacial till. Coarse fragments such as gravel or stones were not present on this spoil. An unmined Ava silt loam soil (Ava fine silty, mixed, mesic Typic Fragiudalf) near the research site was used as the experimental control. It had been in tall fescue (*Festuca arundinacea* (Schreb.) for five years prior to the initiation of this study.

Treatments

The following treatments were employed:

1. Unamended spoil.
2. Replacement of topsoil as required by law over the spoil to a depth of 30 cm.
3. Winter green manure crop of rye cereal (*Secale cereale* L.) and hairy vetch (*Vicia villosa* L.) planted annually each fall.
4. 50 Mg ha^{-1} animal manure (dry weight) incorporated into the surface spoil once.
5. 100 Mg ha^{-1} animal manure incorporated into the surface spoil once.
6. 200 Mg ha^{-1} animal manure incorporated into the surface spoil once.
7. One year old sod crop (planted in 1979) of tall fescue and planted to corn (*Zea mays* L.) in the Spring of 1980.
8. Two year old sod (planted in 1979) and planted to corn in the spring of 1981.

9. Three year old sod (planted in 1979) and planted to corn in the spring of 1982.
10. Unmined Ava silt loam soil (control).

Seedbed Preparation

The animal manure (horse) was applied only once at the beginning of the study and was incorporated into the surface spoil by chiselplowing and disking in the spring of 1979 prior to planting to a depth of about 20 cm. The nutrient analysis of one metric ton of manure was .7 kg of N, .22 kg P and .51 kg K. The sod and green manure crops were planted in the fall of 1978. The green manure crop was disked and plowed under each spring prior corn planting. All sites were limed and fertilized according to soil test requirements. The spoil site received an initial application of 90 kg ha^{-1} N, 90 kg ha^{-1} P, and 112 kg ha^{-1} of K in the fall of 1978. The unmined site received an application of 90 kg ha^{-1} N and 90 kg ha^{-1} of P. Both sites received 12.5 Mg ha^{-1} of limestone in the fall of 1978. Starter fertilizer at the rate of 5 kg N, 11 kg P, and 21 kg K ha^{-1} was applied each year at planting.

Experimental Design

The experiment consisted of ten treatments completely randomized. Each treatment consisted of a plot 9 m by 22 m divided into four quadrants so plant and soil samples could be sampled. True replication was not possible due to the nature and size of the equipment used to add the topsoil. The experimental site originally had a uniform soil free of any gradients such as slope or fertility.

Data was analyzed using the System for Applied Statistics (SAS) program (Barr et al., 1979). A one way analysis of Variance and Duncan's Multiple Range Test were used to identify and separate significant differences among treatments.

Planting

Pioneer 3184 corn was planted in rows 75 cm apart using a hand corn planter. Two or three seeds were planted in hills 30 cm apart within rows, and corn was later thinned to one plant per 30 cm of row for a plant population of 43,500 plants per hectare. The corn was planted in 1979, 1980, 1981, and 1982. However, in 1980 there was a severe drought and therefore no corn yield data was obtained.

Weeds were controlled by use of Lasso (Alachlor) at 2.7 l/ha^{-1} (1.4 kg ha^{-1} a.i.) and Aatrex (Atrazine) at 5.0 l/ha^{-1} (2.5 kg ha^{-1} a.i.).

Corn Tissue Analysis

Corn leaf tissue samples were obtained 26 July 1979. A composite of 20 leaves was taken from each treatment within every sample. Sampling was done after tasseling by taking the first leaf below and opposite the corn ear. Samples were dried, ground in a Wiley Mill with a 2 mm screen. The nitrogen (N) content was determined by the standard Kjeldahl procedure using one half of each sample. Remaining samples were sent to a private laboratory to determine phosphorus, potassium, calcium, magnesium, sulfur, boron, copper, iron, magnesium, and zinc.

Harvest

An area 10 m^2 (2 rows 6.7 m long) from each of four replicates within each treatment was hand harvested. Corn was shelled, weighed, and tested for moisture content and yields were adjusted to a standard 15.5 percent moisture content.

Soil Analysis

Soil organic matter was determined for all treatments from samples taken early each spring at the 0-30 cm depth. Soil samples were air-dried, ground through a 10 mesh sieve, and analyzed using the Wakley-Black Organic Carbon Method (Allison, 1965).

Undisturbed surface soil cores were taken to 30 cm depth before seedbed preparation in the spring of 1979, 1981, and 1982 with an Uhland soil sampler to ascertain bulk densities for each replicate on all treatments. Subsurface (greater than 30 cm) cores were collected prior to the 1982 growing season only. Because it was assumed that the unamended spoil represented a uniform soil material, two sampling sites per treatment were used. Soil moisture percentages were determined to observe soil water depletion by the corn.

RESULTS AND DISCUSSION

The soil organic matter content in the 0-30 cm depth varied widely among treatments (Table 1). The replaced topsoil had a lower initial organic matter content (1.47%) than the unmined Ava soil (2.24%). The replaced topsoil was obtained from a sloping area which previously had some soil erosion, whereas, the unmined Ava soil site was level with little or no erosion. After cropping the control site which had previously been in a tall fescue sod for five years, soil organic matter decreased and then tended to stabilize somewhat. The lowest organic matter level on the mined soil was observed on the unamended spoil. Organic matter percentages tended to increase with increasing manure rates, however, they generally declined somewhat each year following the one time application of manure. There was a slight upward trend in organic matter content from one year sod (four years in cultivation) to the fourth year sod which had not been cultivated. With each additional year that the sod crop was cultivated, the organic amendments from incorporation underwent further decomposition.

In 1983, generally there was a slight increase in the soil organic matter percentages of the treatments over 1982. This may be attributed to the larger supply of fresh organic residues incorporated from the previous year.

Bulk densities were determined for all treatments for the 0-30 cm depth (Table 2). The various organic amendments had only a slight effect on soil bulk densities for all mined spoil treatments. Although the organic matter levels for the manure amended treatments decreased somewhat with time, the bulk densities stabilized at about the same levels. The green manure and sod treatments tended to increase in organic matter content and decreased in bulk density over time. Increased organic matter levels were attributed to yearly additions of plant residues incorporated along with the impact of rooting in the spoil from the grasses and legumes grown which improved soil structure and decreased bulk densities.

Subsurface bulk densities for the mined spoil treatments and the unmined Ava were also obtained (Table 3). Bulk densities varied slightly from 1.71 g/cc to 1.75 g/cc on the mined spoil. This was much higher than on the unmined Ava soil which ranged from 1.48 g/cc to 1.52 g/cc. These higher bulk densities severely restricted root penetration and impeded water movement.

Leaf tissue analyses of corn grown on amended spoil of mined prime farmland

are presented in Table 4. It appears from the corn tissue analyses that plant nutrients were not a limiting factor in grain production on any treatment (Vitosh et al. 1973). These results suggest that there were adequate amounts of available nutrients in the spoil which were taken up by the corn.

Corn grain yields are given for 1979, 1981 and 1982 in Table 5. There was a severe drought in 1980 resulting in the loss of the entire crop. In 1979, corn grain yields were increased significantly over the unamended spoil by incorporating animal manure into the surface spoil. Grain yields on the 100 and 200 Mg ha^{-1} animal manure treatments were comparable to the unmined Ava silt loam treatment. Grain yields on the unamended spoil in 1979 were comparable to the topsoil replacement treatment. During this cropping season, however, the corn on the topsoil replacement treatment grew off faster than on the unamended spoil and encountered a severe dry spell at pollination. This resulted in lower grain yields on the replaced topsoil treatment. In subsequent years, there were no real differences in yield between these two treatments probably due to the fact that fresh organic residues were being added each year to the unamended spoil. The green manure treatment gave the lowest corn grain yield in 1979.

The organic amended treatments (animal manure, green manure and sod) gave higher corn grain yields than the topsoil replacement in both 1981 and 1982. This difference may be due to the potentially higher productivity of the amended spoil material. Pollination of the corn on the topsoil replacement treatment was also earlier than that on the organically amended spoil treatment when moisture conditions were more favorable.

Soil moisture percentages indicated that the rooting depth of the corn in the mined spoil was limited to the depth of chiseling (30-40 cm). The rooting depth of the unmined Ava soil was approximately 75 cm, the depth of the impermeable fragipan which accounts for some of the yield differences.

Organically amended spoil may provide a more favorable rooting medium for corn production than unamended spoil. While spoils generally lack nitrogen because of the loss of topsoil with its organic matter, this deficiency may be rectified with the addition of organic amendments (Fail and Wochok, 1977). The addition of manures to soils may also increase water intake (Hafez 1974 and Meek et al. 1982).

CONCLUSION

When bulk densities and compaction problems can be minimized through improved reclamation techniques, organic amendments and a mixture of B and C-horizons in lieu of topsoil replacement may provide a possible alternative to the segregation and replacement of A, B, and C soil horizons in the reclamation of mined prime farmland. However, crop production may be less than on unmined soil.

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Table 1. Mean percentages of soil organic matter for the 0-30 cm depth for all treatments on mined prime farmland in 1979, 1981, 1982, and 1983.

	Organic Matter			
Treatment	1979	1981	1982	1983
	..... %			
Unamended Spoil	0.38a*	0.31a	0.30a	0.40a
Green Manure	0.48a	0.37a	0.44a	0.81cde
50 Mg ha^{-1} Manure	0.97b	0.48a	0.37a	0.76bc
100 Mg ha^{-1} Manure	1.29c	0.88b	0.71ab	0.93e
200 Mg ha^{-1} Manure	1.96d	1.58c	1.23c	1.23f
1 Year Sod	—	0.49a	0.43a	0.71b
2 Year Sod	—	0.67ab	0.54a	0.73b
3 Year Sod	—	—	0.77b	0.76bc
4 Year Sod		—	—	0.91cde
Topsoil Replacement	1.47c	1.33c	1.35c	1.29f
Unmined Ava Soil	2.24	1.53	1.57	1.66

*Means in the same column followed by similar letters are not significantly different at the 0.05 level according to Duncan's Multiple Range Test.

Table 2. Mean soil bulk densities for the 0-30 cm depth for all treatments on mined prime farmland in 1979, 1981, 1982.

Treatment	Bulk Density		
	1979	1981	1982
	..... g/cc		
Unamended Spoil	1.60a*	1.54a	1.50ab
Green Manure	1.56a	1.47a	1.48abc
50 Mg ha^{-1} Manure	1.54a	1.50a	1.54a
100 Mg ha^{-1} Manure	1.40b	1.49a	1.47abc
200 Mg ha^{-1} Manure	1.32b	1.49a	1.48abc
1 Year Sod	—	1.48a	1.47abc
2 Year Sod	—	1.43a	1.42cd
3 Year Sod	—	—	1.44bc
Topsoil Replacement		1.45a	1.42cd
Unmined Ava Soil	1.32	1.33	1.35

*Means in the same column followed by similar letters are not significantly different at the 0.05 level according to Duncan's Multiple Range Test.

Table 3. Mean soil bulk densities 30-120 cm depths for all treatments on mined prime farmland in 1982.

Surface — mined Site		Unmined Ava Soil	
Depth cm	Bulk Density g/cc	Depth cm	Bulk Density g/cc
30-60	1.71	20-75	1.48
60-90	1.75	75-120	1.52
90-120	1.72		

Table 4. Leaf tissue analyses of corn grown on amended spoil of mined prime farmland (26 July, 1979).

Treatment	N	P	K	Ca	Mg	B	Cu	Fe	Mn	Zn
			%					ppm		
Unamended Spoil	2.74ab*	.26a	2.60b	.31b	.25abc	10.0a	20.0bc	121.3a	60.5b	33.0ab
Green Manure	2.53bc	.26a	2.37b	.31b	.26ab	9.3a	21.0ab	158.5a	79.3ab	39.5a
50 Mg ha^{-1} Manure	2.73ab	.24a	2.63b	.33b	.22cd	7.7a	19.5bc	123.7a	80.5ab	32.7ab
100 Mg ha^{-1} Manure	2.49c	.26a	3.05a	.32b	.18de	9.7a	17.0d	134.0a	59.3b	27.0c
200 Mg ha^{-1} Manure	2.60abc	.27a	2.59b	.35b	.15e	10.0a	18.7c	137.0a	53.7b	28.0c
Topsoil Replacement	2.74ab	.24a	1.91c	.34b	.29a	8.0a	21.0ab	132.3a	102.5a	27.3c
Unmined Ava Soil	2.77	.26	1.95	.48	.24	7.5	22.3	133.0	56.7	29.3

*Means in the same column followed by similar letters are not significantly different at the 0.05 level according to Duncan's Multiple Range Test.

Table 5. Mean corn yields (15.5% moisture) for all treatments on mined prime farmland in 1979, 1981, 1982.

Treatment	Corn Grain Yield		
	1979	1981	1982
	.....kg/ha^{-1}.....		
Unamended Spoil	6,892b*	5,666bcd	5,644bcd
Green Manure	5,941c	7,094a	6,368ab
50 Mg ha^{-1} Manure	7,374b	6,822abc	4,967cd
100 Mg ha^{-1} Manure	8,257a	7,424a	6,693ab
200 Mg ha^{-1} Manure	8,649a	6,794abc	6,717abc
1 Year Sod	—	6,576abc	7,065ab
2 Year Sod	—	5,305cd	7,673a
3 Year Sod	—	—	6,868ab
Topsoil Replacement	6,852b	4,724d	4,254d
Unmined Ava Soil	8,245	9,496	7,124

*Means in the same column followed by similar letters are not significantly different at the 0.05 level according to Duncan's Multiple Range Test.

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A REEXAMINATION OF THE LEAF OF ACTINOXYLON BANKSII

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ABSTRACT

Differences in interpretation of the nature of the leaf of *Actinoxylon banksii* have stimulated a reexamination of the leaf. Serial transverse sections of a leaf of the holotype show that there is a rotation of the leaf base so that the leaf is oriented in a plane tangential to the stem surface. The leaf base divides three times. The first two divisions are in the tangential plane and the third is in the radial plane, producing a three-dimensional unit.

INTRODUCTION

Actinoxylon banksii Matten (Matten, 1968) is an upper Middle Devonian (Givetian) member of the Archaeopteridales. The plant is preserved as a pyrite permineralization and all interpretations of external form are based on reconstructions from serial sections. Its protostelic stem, helical arrangement of branches, and non-planated and non-webbed leaves were considered sufficient to separate this taxon from the more completely known *Archaeopteris*. The lack of information about the reproductive morphology of *Actinoxylon* is also a reason for keeping it distinct from *Archaeopteris*.

Speculation on variability and overlap of vegetative features of *Archaeopteris*, *Actinoxylon*, *Svalbardia*, *Eddya*, and *Actinopodium* has led to the possibility that these genera within the Archaeopteridaceae represent component parts of a single variable genus, *Archaeopteris* (Beck, 1969, 1970, 1976). The original reconstruction of *Actinoxylon* (Matten, 1968) illustrated the leaf as being somewhat flexuous and branching in three-dimensions. This leaf morphology is an important distinction between *Actinoxylon* and *Archaeopteris*. Using illustrations from the original paper on *Actinoxylon*, Beck presented a reconstruction of an *Actinoxylon* leaf that ap-

pears planated and thus, more similar to the leaf of *Archaeopteris* (Beck, 1969, figure 9). Beck's figure was repeated in subsequent papers (Beck, 1970, 1976).

In 1981, *Svalbardia banksii* was described from the lower Upper Devonian (Frasnian) of New York (Matten, 1981). This species is preserved as a compression and is displaced in three dimensions within the entombing rock matrix. The reconstruction shows the leaves to be flexuous, unwebbed and forking in three-dimensions. This is the first compression member of the Archaeopteridaceae to demonstrate three dimensional branching of the leaves. The study of *Svalbardia banksii* stimulated the writer to return to the type specimen of *Actinoxylon banksii* in order to reexamine the sections of the leaves and to make a comparison of their morphology with that of the closely comparable *Svalbardia banksii.*

MATERIALS AND METHODS

The holotype of *Actinoxylon banksii* is housed in the Southern Illinois University Paleobotanical Collection in the Department of Botany and bears the number CQ 17. The type consists of 49 slides and one small, uncut piece. The slides consist of polished and etched slices of pyrite (Matten, 1968) and were examined using reflected light and a Bausch and Lomb stereomicroscope. Drawings were initially made with a Nikon Contour Projector. The drawings were then digitized with a Summagraphics drawing pad attached to a Macintosh 512E computer and arranged into figures 1 and 2. All descriptions of sections are based on transverse views of the fossil. The composite illustration of serial drawings is provided to show both the twisting nature of the leaf and the plane of division of the first three forkings of the leaf (fig. 2).

RESULTS

The most complete leaf was selected for description and drawing. This leaf extended from its decurrent ridge (CQ 17, section 4; fig. 1-4) to a point where it had divided into 8 units (CQ 17, section 25), a distance of about 5 cm.

At the lowest level (fig. 1-4) the oval trace appears below a bulge in the surface of the stem. The bulge is interpreted as a decurrent ridge. In section 6 (fig. 1-6), the base of the leaf is almost free from the stem surface and contains the trace. In section 8 (fig. 1-8), a constriction appears in the xylem strand of the trace. The dividing xylem strand is elongated in the radial plane.

In section 10 (fig. 1-10), the xylem strand of the trace is divided into two terete strands. The two terete strands are oriented slightly obliquely to the stem surface. In section 14 (fig. 1-14) the leaf base is almost detached from the stem. The two terete traces are displaced from each other and are oriented in a plane that is obliquely tangential to the surface of the stem. In section 16 (fig. 1-16) the leaf base is at the point of detachment from the stem. A constriction appears in the leaf base, separating the two xylem strands. Each of the two xylem strands is also constricted, the constriction being oriented so that each xylem strand is elongated in the tangential plane.

In section 18 (fig. 1-18), the leaf base is now divided into two segments, each tangentially displaced from the other. Each leaf segment has two tangentially

displaced xylem strands. In section 20 (fig. 1-20), each of the two leaf segments is elongated in the tangential plane and possesses a median constriction.

Section 22 (fig. 1-22) shows that the leaf is now divided into four tangentially oriented segments. The uppermost segment is occupied by two terete xylem strands. The two xylem strands are oriented in the radial plane, in relation to the stem. Each of the other leaf segments is occupied by a single terete xylem strand. Section 24 (fig. 1-24) shows the four leaf segments elongated in the radial plane. The uppermost and lowermost segments are constricted and contain a terete xylem strand on each side of the constriction. Of the two middle leaf segments, the upper one shows a single radially-elongate xylem strand with a median constriction. The lower of the two middle leaf segments is radially elongate and contains two radially oriented xylem strands.

Section 25 (fig. 1-25) shows that the leaf is now divided into seven segments. The two uppermost segments and the two lowermost segments are radially displaced. Of the middle segments, the uppermost one is radially elongate and contains two radially displaced xylem strands. The other two middle segments each contain a single terete xylem strand and are tangentially displaced. These latter two segments represent the lower middle segment of section 24. A reconstruction of the leaf based on the superposition of the sections just described shows its three-dimensional organization (fig. 2)

DISCUSSION

The reexamination of the morphology of the leaf of *Actinoxylon banksii* points out two significant morphological features. First is the change in orientation from a radially produced xylem strand to a tangentially displaced unit. Second is the planes of division of the leaf segments.

The rotation of the leaf trace into a tangentially displaced unit as seen in sections 4-14 (figs. 1-4 to 1-14) demonstrates how the progymnosperm and early gymnosperm pattern of leaf trace formation (Namboodiri and Beck, 1968c) may have developed into the pattern seen in later gymnosperms (Namboodiri and Beck, 1968a,b). The rotation of the trace seen in *Actinoxylon* conforms to the model illustrated by Namboodiri and Beck (1968c). Precocious development of the tangential displacement of the xylem strand in the stele and its subsequent genetic fixation would result in the patterns we observe today.

Branching of the leaf segments occurs in both tangential and radial planes. After the initial rotation of the basal leaf segments, there are two divisions in the tangential plane resulting in four axes. The third division in at least three of these axes is in the radial plane. The fourth axis (fig. 1-24, second axis from bottom) shows a radial orientation in sections 22-24 but in section 25 is oriented in the tangential plane. This is most likely due to twisting during burial and represents an artifact. The parenchymatous nature of these leaf segments contributes to the interpretation that these segments were flexuous and were susceptible to twisting.

The leaves of *Svalbardia banksii* are very similar to those of *Actinoxylon*. The most complete leaf of *Svalbardia banksii* shows a decurrent ridge on the stem. The first two divisions of the leaf base are in the tangential plane while the third division is in the radial plane. This is one more similarity between the two taxa. However,

only petrified *Svalbardia banksii* showing *Actinoxylon banksii* anatomy will justify the two being placed in synonymy.

SUMMARY

The rotation of the leaf base and the three-dimensional character of the leaf of *Actinoxylon banksii* have been demonstrated. Reconstructions of *Actinoxylon banksii* have been demonstrated. Reconstructions of *Actinoxylon* should be based on Matten (1968) and not Beck (1969). The characters of the leaf continue to separate the genus from *Archaeopteris* and serve as a basis for examining morphological change within the family.

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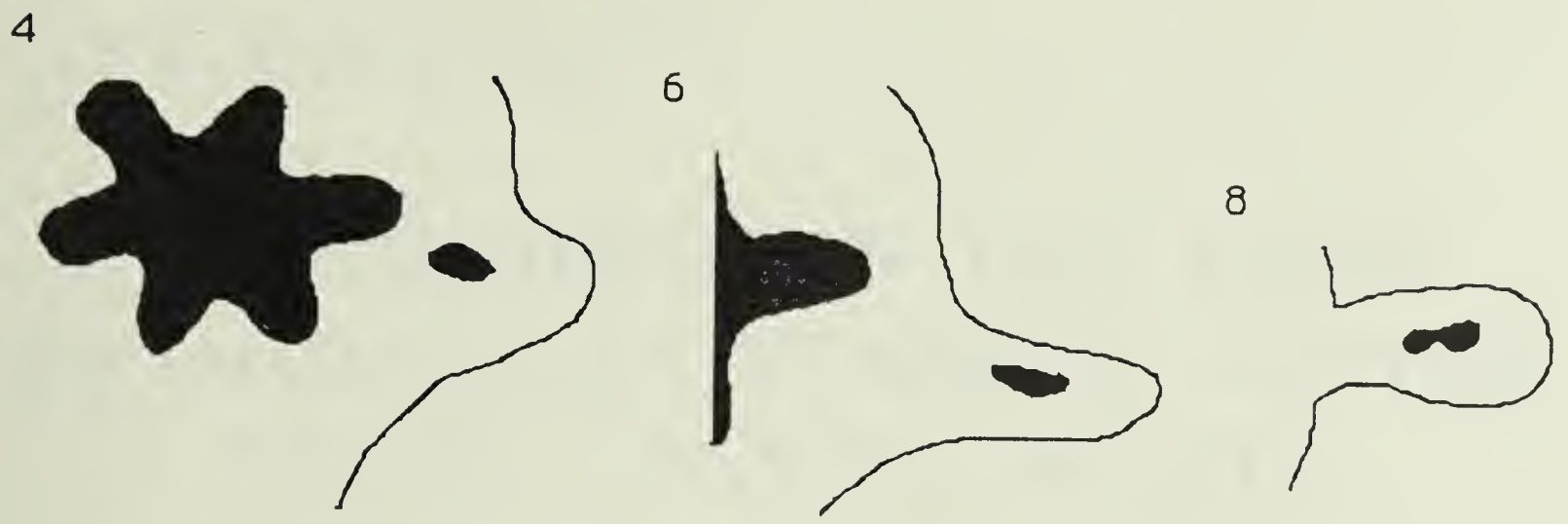

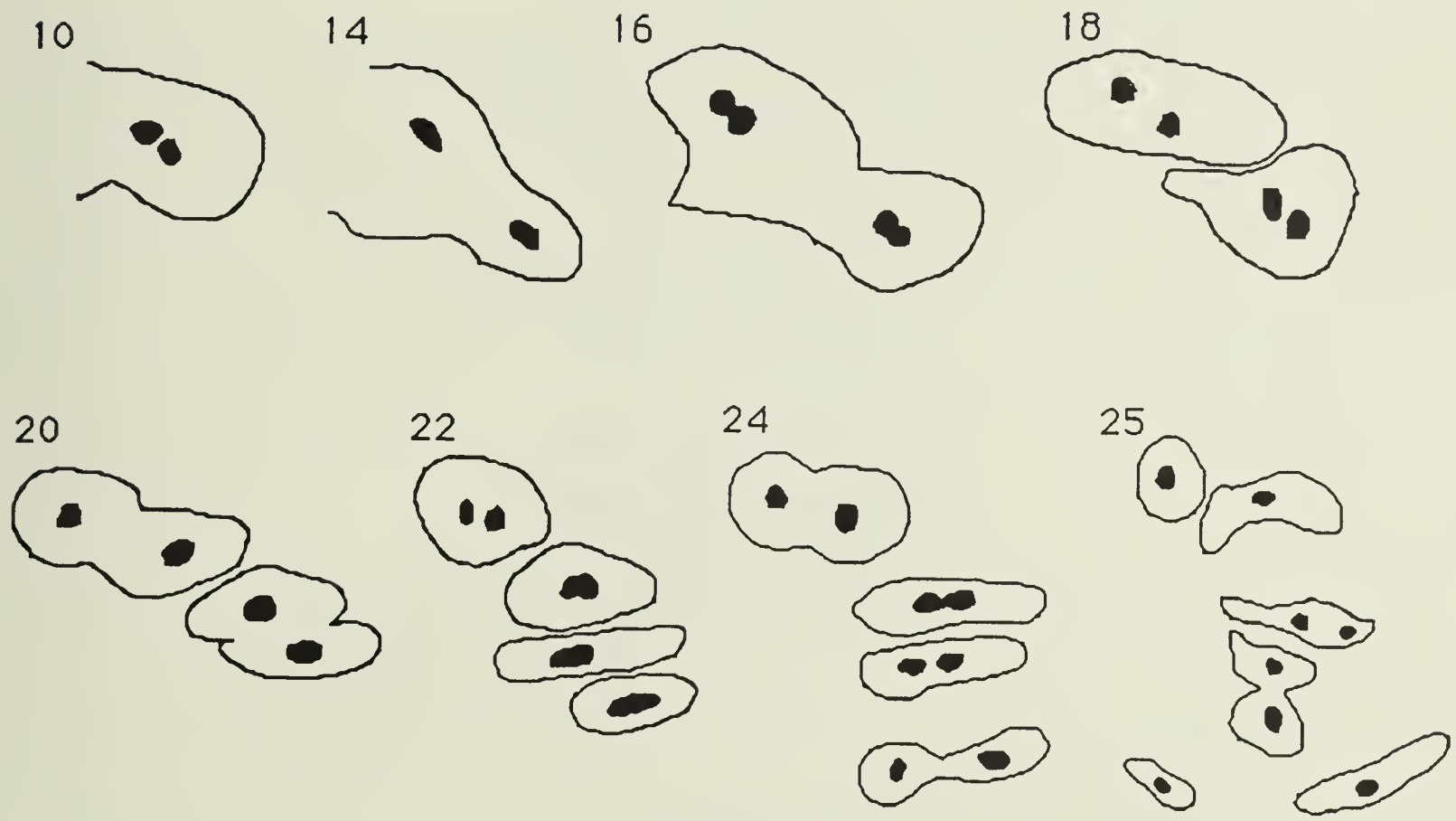

Figure 1. Serial transverse sections of leaf of *Actinoxylon banksii* holotype (Southern Illinois University Paleobotanical Collection — CQ 17). Black areas represent primary xylem. Numbers refer to the specific section of the specimen. All sections are oriented in the same manner. All sections are drawn at approximately X 9.5 normal size.

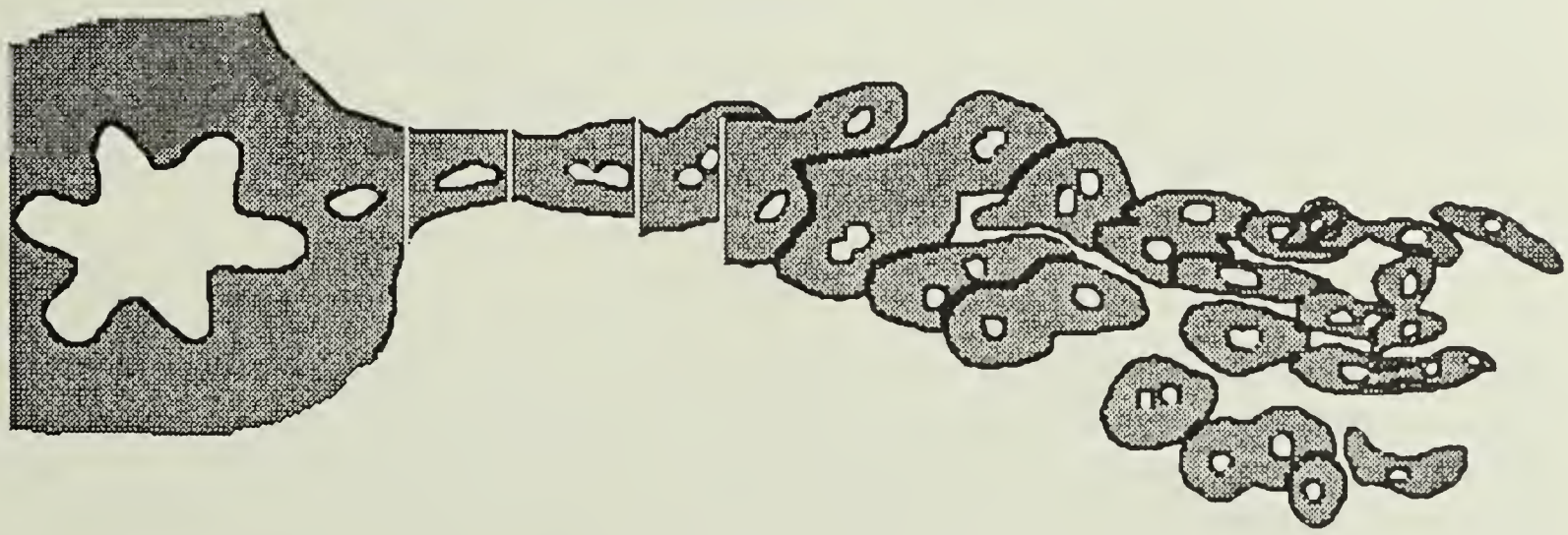

Figure 2. Reconstruction of leaf of *Actinoxylon banksii* holotype (Southern Illinois University Paleobotanical Collection — CQ 17) based on serial transverse sections shown in fig. 1. White areas represent primary xylem. All sections are oriented in the same manner.

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BRACHIOPODS IN THE BASAL DESMOINESIAN AT ARROW CANYON, CLARK COUNTY, NEVADA

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ABSTRACT

Antiquatonia hermosana, Echinaria knighti, Composita ovata, Anthracospirifer curvilateralis sub sp. nov., *Anthracospirifer opimus*, and *Neospirifer alatus*, occur in the lowermost Desmoinesian of the Bird Spring Group at Arrow Canyon, Clark County, Nevada. The well-exposed, readily accessible Arrow Canyon section is under consideration for a possible Atokan-Morrowan boundary stratotype. As a consequence detailed information regarding the systematics and biostratigraphy of basal Desmoinesion brachiopods at this locality is needed.

INTRODUCTION

The Bird Spring Group at Arrow Canyon is exceedingly well-exposed and readily accessible. It also apparently is the product of essentially continuous deposition from the Chesterian into the Wolfcampian. As a consequence, a continuing program has been undertaken to systematically describe the brachiopod fauna,

develop a reference section for brachiopod biostratigraphy in the Cordilleran miogeosyncline, and determine the environmental limits on brachiopod occurrence in carbonate depositional environments (Langenheim, Huff, Lipman and Vaiden, 1983; Langenheim, Huff, Lipman, Moffett and Vaiden, 1985). This paper systematically describes the more prominent early Desmoinesian brachiopods above the late Atokan fauna described by Huff (1984) and below the Desmoinesian brachiopods described by Moffett (1986). In addition the stratigraphic distribution of these fossils is determined. These data are of immediate application to the search for a Morrowan-Atokan boundary stratotype.

Field work was accomplished at Arrow Canyon in January, 1986. Slabs were collected from all units with visible fossils and brought back to the laboratory where silicified fossils were recovered by etching in hydrochloric acid. Unsilicified materials remain unstudied.

Arrow Canyon is at the northern end of the Arrow Canyon Range, E½ section 11, S½ section 12, T14S, R64E, and SE¼ section 7, T14S, R65E, Clark County, Nevada, about 50 miles northeast of Las Vegas (Fig. 1). It is reached by exiting Interstate 15 at Glendale, Nevada and heading northwest on Nevada Route 168, then turning left on a paved secondary road at the northern edge of the irrigated land along the Muddy River. After 200 yards turn right on a jeep trail and follow it up the canyon about 3 km to the collection site on the north wall. This site is about 1 km below the mouth of the narrow gorge.

STRATIGRAPHY

The Bird Spring Group consists of about 2,100 feet of cherty limestone, sandy limestone, dolomite, and shale, and contains abundant silicified fossils. The group has been divided into five formational units at Arrow Canyon (Larson and Langenheim, 1979; and Langenheim and Langenheim, 1965). These include, from the lowest up: the Battleship Wash Formation; the Indian Spring Formation; and three informal units: BS_c, BS_d and BS_e. These strata range from the Chesterian to Wolfcampian.

The stratigraphic sequence under consideration includes VAL Units 135 through 151 (Fig. 2). The VAL Units are lithologic subdivisions of the stratigraphic column first defined by Langenheim and Langenheim (1965) in their reconnaissance of the Bird Spring Group. These units subsequently have been utilized by investigators in our group. In this report we do not separately recognize and describe each VAL unit and some have been grouped, as in VAL 139/140/141 undifferentiated, for description and interpretation. In addition, the original measurements of Langenheim and Langenheim (1965) have been discarded and the VAL unit boundaries and thicknesses have been related to a surveyed series of monuments set at stratigraphic intervals of 1.5 meters throughout the Chesterian and Pennsylvanian part of the Bird Spring Group by geologists of the AMOCO company. Figure 2 indicates the position of unit boundaries and AMOCO monuments along the line of section studied by us on the north wall of the canyon.

The section described in this report is entirely within the BSc unit and is dominated by well-indurated calcilutitic to calcisiltitic limestone with abundant chert concretions. Interbedded, more shaly limestone, generally contains less chert

(Fig. 3). Our lithologic descriptions of the units in the measured section follow (Units are numbered in order from the base upwards):

VAL 149/150/151 (undifferentiated): Interbedded, fine- to very-fine grained limestone comprised of four massive layers alternating with 5 shaly layers; massive layers contain rusty gray chert nodules; moderately to sparsely fossiliferous; light gray weathering to light tan; forms reentrant; 7′5″ thick.

VAL 148: Massive, very resistant, fine-grained limestone; intermittent rusty to gray, cobble size chert nodules; abundantly fossiliferous in uppermost 12″, generally less fossiliferous in lower parts; light gray weathering to dark gray; moderately abundant white calcite veins; bench former; 5′0″ thick.

VAL 147: Very friable silty limestone containing very abundant cobble size chert nodules; moderately to sparsely fossiliferous; whiteish-gray weathering to whiteish-gray; forms reentrant; lower half partially covered; 5′4″ thick.

VAL 146: Massive, very resistant, medium- to fine-grained limestone; abundant cobble size to larger chert nodules; abundantly fossiliferous; dark gray weathering to dark gray; scattered calcite veins; bench former; 3′0″ thick.

VAL 144/145 (undifferentiated): Thick bedded, fine-grained limestone containing very abundant cobble size to smaller dark chert nodules; moderately fossiliferous; gray weathering to tan; scattered white calcite veins and vugs; bench former, but less resistant than unit VAL 146; 11′6″ thick.

VAL 143: Very friable silty limestone containing a few small chert nodules; moderately to abundantly fossiliferous; gray weathering to gray; forms reentrant; gradational upper contact with unit VAL 144/145; 2′2″ thick.

VAL 142: Massive, very resistant, fine-grained limestone containing intermittent, distinctive, very large black chert nodules up to 3 feet in diameter; fossiliferous with abundant fusulinids; gray weathering to dark gray; abundant white calcite veining; bench former; 6′2″ thick.

VAL 139/140/141 (undifferentiated): Nodular massive to shaly, fine-grained, argillaceous limestone; discontinuous layering of cobble to smaller size, orange brown chert; complete fossils are scarce; gray weathering to tannish gray; less resistant near base; irregular bench former; partially covered at base; 7′8″ thick.

VAL 137/138 (undifferentiated): Resistant, fine-grained limestone with few chert nodules; thick bedded near base, thin bedded towards top; abundant fossil fragments; dark gray weathering to gray with buff patches; 9′8″ thick.

VAL 136: Interbedded, fine- to very-fine grained limestone comprised of 3 massive beds alternating with 3 shaly layers; brown to black cobble size chert nodules in massive layers; moderately fossiliferous; abundant fusulinids in the second massive layer from the top; dark gray weathering to gray; forms reentrant; 9′10″ thick.

VAL 135: Massive, resistant, fine-grained limestone; few chert nodules; moderately to sparsely fossiliferous; gray weathering to brownish-gray with rusty-brown chert; moderate white calcite veining; bench former; 2′3″ thick.

BRACHIOPOD SYSTEMATICS

Systematics in this paper are those of the Treatise on Invertebrate Paleontology, Part H, Brachiopoda (Moore, 1965).

Order Strophomenida Opik, 1934
Suborder Productidina Waagen, 1883
Superfamily Productacea Gray, 1840
Family Dictyoclostidae Stehli, 1954
Subfamily Dictyoclostinae Stehli, 1954
Genus *Antiquatonia* Miloradovich, 1945
Antiquatonia hermosana Girty, 1903

Figs. 4-10

Products semireticulatus var. *hermosana* Girty, 1903, p. 358, pl. 11, figs. 1-4b.
Antiquatonia hermosana Hoare, 1961, p. 56, pl. 6, figs. 1-3; Lane, 1962, p. 901, pl. 126, figs. 5-8; Sutherland and Harlow, 1973, p. 51, pl. 11, figs. 6-12.

Description: The medium-sized shells are semicircular to subrectangular in outline. The pedicle valve is strongly convex but not geniculate, appearing approximately semicircular from the side. The maximum width is at the hingeline, and maximum height is slightly posterior to midlength. The hingeline is straight terminating in distinct flattened to dorsally curved ears, which abut anterolaterally against steeply rising flanks.

Radial ornamentation of low rounded costae averages about 13 per 10mm. (measured 15mm. anterior to umbo). Costae are evenly spaced and continuous from umbo to anterior, and unaffected by intervening spines. Bifurcation is rare to absent with costae becoming more coarse and widely spaced as they near the anterior. Concentric rugae impart a faint reticulate pattern most pronounced in the posterior third of the valve.

The beak is small and overhangs the hingeline very slightly, if at all. A broad, shallow sulcus originates at about 3/5 the length from the posterior, and widens slightly and deepens toward the anterior.

The spines are concentrated primarily on the venter. Some also are scattered along the flanks and the anterior portion of the valve.

Dendritic adductor scars are separated by a median sinus. Rod-like adductor platforms converge at midlength into a small sub-ovate lobe. Longitudinal lineations on the diductor scars continue laterally ¾ the way to the margin.

The dictyoclostid cardinal process is dorsally trilobed with the two outer lobes flaring around the middle lobe. From the posterior, the process appears ovate with a U-shaped depression between the middle and outer lobes. Pronounced lateral ridges diverge from the base of the cardinal process, roughly parallel the hingeline and angle slightly anteriorly. Pronouncedly dendritic raised adductor platforms are separated by a low median septum which becomes blade-like about 5mm. anterior of the base of the cardinal process. The cardinal processes described were not associated with complete valves as collected, but were matched to accompanying.

A. hermosana specimens by size and form.

Specimen	Length	Width	Height	Costae*
X6668	30.5mm	40.0	15.0mm	13
X6669	29.0mm	36.0	14.5mm	13
X6670	38.5mm	43.0	24.0mm	12

*per 10mm at 15mm from umbo

Discussion: Scattered spines on the flanks and venter of the Nevada specimens distinguish them from *Dictyoclostus,* which has patches of spines on its flanks (Muir-Wood and Cooper, 1960), and from *Inflatia,* which has a single row of spines along the hingeline. Furthermore, the specimens have only a few subdued rugae near the pedicle posterior, whereas *Dictyoclostus* is rugate over most of its pedicle valve.

The species most similar to the Arrow Canyon *A. hermosana* is *A. coloradoensis* (Girty). *A. coloradoensis,* however, reportedly averages 17.5 costae per 10mm (at 20mm), whereas *A. hermosana* averages 13 (Sutherland and Harlow, 1973). The relatively coarse, regular costae and strongly arched ears help to distinguish the Arrow Canyon specimens from *A. portlockiana* (Norwood and Pratten), and *A. portlockiana* var. *crassicostata* (Dunbar and Condra). The Nevada specimens also are much larger. *A. costellata* lacks the ventral spines and relatively coarse costae of the Arrow Canyon specimens.

Materials and Occurrence: This species is well represented by eight specimens in VAL unit 146. Three of these (hypotypes X6668, X6669, and X6670) are well preserved and five are fragmentary. One poorly preserved specimen of *A. hermosana* also was observed in VAL unit 136. Several cardinal processes similar to those described for *A. hermosana* occur in residue from these units, and are assumed to belong to *A. hermosana,* although not attached to complete specimens.

Family Echinoconchidae Stehli, 1954
Subfamily Echinoconchinae Stehli, 1954
Genus *Echinaria* Muir-Wood and Cooper, 1960
Echinaria cf. *E. knighti* Dunbar and Condra, 1932

Figs. 11-16
Echinaria cf. *knighti,* Sutherland and Harlow, 1973, p. 47, pl. 9, figs. 4-7.

Description: These large to medium sized shells are highest at about ¼ the length from the posterior, and widest near midlength. Their general outline is subrectangular to ovate.

The pedicle valve is strongly convex, but not geniculate. Convexity increases posteriorly and is greatest at the umbo. Ears are small and flanks are steep and pronounced. The umbo is inflated and the tapering beak greatly overhangs the hingeline. A broad, shallow sulcus arises slightly anterior to the beak and extends to the anterior margin of some specimens. Concentric bands of prostrate spines (2 and 3 rows) alternate with shallow transverse furrows. The bands generally are regular and closely spaced (about 1 to 1.5mm) and are apparent along the entire length of the valve. Their spacing decreases toward the anterior and becomes very close near the anterior margin. Pedicle interior not observed.

The pronounced cardinal process is divided at its posterior into two ridge-like lobes separated by a deep median sulcus. On the brachial interior, well developed ridges extend laterally from the base of the process at nearly right angles and continue to the ears. A thin blade-like median septum, originating at the base of the process, protrudes dorsally. It extends anteriorly between two raised dendritic adductor muscle platforms, but becomes indistinguishable at midlength. Concentric rows of endospines are unobserved throughout the brachial interior.

Specimen	Length	Width	Height
X6671	65.5mm	47.0mm	35.0mm
X6672	60.0mm	55.0mm	46.0mm
X6673	29.0mm	27.0mm	13.0mm

Discussion: The Arrow Canyon specimens closely resemble *E. semipunctata* (Shepard), but are distinguished by their ovate to subrectangular outline, less pronounced umbo, shallower sulcus, and more rounded beak. *E. knighti* also is generally smaller than *E. semipunctata* which averages 8 to 9cm long (Dunbar and Condra, 1932). *E. knighti* averages 5 to 6cm long although Sutherland and Harlow (1973) report specimens as much as 7cm long.

Materials and Occurrence: Two moderately well preserved specimens (hypotypes X6672 and X6673) were recovered from VAL unit 148, and one well preserved specimen (hypotype X6674) from VAL unit 136 display the pedicle valve only. One well preserved brachial valve (hypotype X6671) from VAL unit 136 is embedded in limestone, obscuring the exterior.

Order Spiriferida Waagen, 1883
Suborder Athyrididina Boucot, Johnson, and Staton, 1964
Superfamily Athyridacea M'Coy, 1884
Family Athyrididae M'Coy, 1884
Subfamily Athyridinae M'Coy, 1884
Genus *Composita* Brown, 1849
Composita ovata Mather, 1915
Figs. 17-22

Seminula subtilita, Girty, 1903, pl. 7, figs. 2, 2a (not 1, 3-10).
Composita ovata, Dunbar and Condra, 1932, p. 370-371, pl. 43, figs. 14-19; Gehrig, 1958, p. 13, pl. 5, figs. 5-13, 24-27, 38-40; Hoare, 1961, p. 90-91, pl. 2, figs. 6-9; Stevens, 1962, p. 620, pl. 91, fig. 5; Grinnell and Andrews, 1964, p. 234; Sturgeon and Hoare, 1968, p. 57-58, pl. 18, figs. 11-18; Sutherland and Harlow, 1973, p. 64-67, pl. 14, figs. 18-21b.
Composita subtilita var. *ovata*, Burk, 1954, p. 12-13, figs. 2-4.

Description: Shell is medium sized and biconvex with the pedicle valve only slightly more convex longitudinally than the brachial valve. Both valves are more strongly convex posteriorly with the greatest curvature near the umbo and gently decreasing anteriorly. The shell is nearly evenly biconvex transversely, with neither the fold nor the sulcus significantly altering the outline. The shell is longer than wide with the maximum width slightly anterior to midlength, and the maximum height at about ¾ the length toward the posterior. The outline is ovate with a stretched and inflated umbo protruding about 5mm posteriorly outside the extrapolated margin.

The beak is recurved but does not protrude dorsally through the commissural plane. It is perforated at the tip by a posterodorsally directed circular foramen opening anteriorly to a partially exposed triangular delthyrium.

A broad, shallow sulcus originates on the pedicle valve at about ¼ the length from the umbo and widens and deepens slightly toward the anterior. A very faint line in the center is most visible near the anterior end. The posterolateral margins diverge at an angle of approximately 96 degrees. Concentric ornamentation consists of spaced, accentuated growth lines, with the interlinear distance progressively increasing anteriorly and then decreasing abruptly near the margin.

The brachial valve is nearly the same size as the pedicle valve excepting the umbonal area. A ill-defined fold is apparent at the posterior margin but is undetectable at midlength. The concentric growth lines are somewhat more irregularly spaced than on the pedicle valve.

The dimensions of the only well preserved specimen are: length 26.5mm; width 26.0mm; height 16.5mm.

The interior of the specimens is inaccessible.

Discussion: The shallow fold and sulcus of the Arrow Canyon specimens distinguish them from *C. argentea* (Shepard), as well as from *C. girtyi* (Raymond) and *C. elongata* (Dunbar and Condra) which are also more elongate and more convex. The species most similar to the Arrow Canyon species is *C. subtilita* (Hall), which is generally more elongate and has a more pronounced fold and sulcus than *C. ovata*, although the gradation between their external morphologies is imperceptible in some large collections (Sutherland and Harlow, 1973).

Materials and Occurrence: This species is moderately well represented with one complete specimen (hypotype X6677) and two well preserved internal molds (including hypotype X6675) from VAL unit 146. One complete but deformed specimen (hypotype X6676) also was recovered from VAL unit 149, and many fragments were recovered from both units.

Suborder Spiriferidina Waagen, 1883
Superfamily Spiriferacea King, 1846
Family Spiriferidae King, 1846
Genus *Anthracospirifer* Lane, 1963
Anthracospirifer curvilateralis sub sp. nov.
Figs. 23-24

Description: The medium-sized shell is biconvex with distinctive, greatly extended, cardinal margins giving it an alate outline. The shell is 30.4mm wide, 12.1mm long, and approximately 6.5mm high. The umbo is inflated and the beak overhangs the hinge line by 2.5mm.

The sulcus contains five costae, all of which, excepting the middle, arise from the primary costa. The lateral slope is gently concave with 11 costae, all of which are simple, excepting the first which arise from the primary costa.

Preserved interiors or brachial valves were not found.

Discussion: This subspecies is distinguished from all other *Anthracospirifer* spp. by its alate (wing-like) outline (Moffett, 1986). *A. newberryi* (Sutherland and Harlow) and *A. birdspringensis* (Lane) are alate, but their width to length ratios are much less than that of the specimen.

Materials and Occurrence: A well-preserved pedicle valve (hypotype X-6678) was collected from VAL unit 144/145 (undifferentiated). Moffett's holotype was found in VAL unit 166 at Arrow Canyon, approximately 50m above VAL unit 144/145 in Lower Desmoinesian strata.

Anthracospirifer opimus (Hall) 1858
Figs. 25-27

Spirifer opimus Hall and Whitney, 1858, p. 711, pl. 28, figs. la-b; Dunbar and Condra, 1932, p. 320-322, pl. 41, figs. 10-11c; Hoare and Burgess, 1960, p. 713-714, pl. 91, figs. 4-5; Spencer, 1967, p. 16-18, pl. 9, figs. la-f.
Anthracospirifer opimus Sturgeon and Hoare, 1968, p. 62, pl. 19, figs. 30-32; Moffett, 1986, p. 102-104, pl. 16, figs. 11-12; Huff, 1984, p. 122-126, pl. 7, figs. K-N.
Anthracospirifer "opimus" Sutherland and Harlow, 1973, p. 85-86, pl. 16, figs. 17-19.

Description: The medium-sized shells are strongly biconvex. Average dimensions are 20.5mm wide, 17mm long, and 13.2mm thick. The anterior margin is semicircular and the shell is widest at the hinge line. The umbo is inflated and overhangs the hingeline 3.1mm.

The pedicle sulcus is bounded by two primary costae originating at the beak. It is moderately deep and contains three costae of which the outer two arise from the primary costa. The lateral slope is convex and bears 9-10 simple costae. The inner 6-7 originate from the beak but the outer 3-4 start from the hinge line.

The fold is deformed on the only preserved brachial valve (hypotype X6679), but the lateral slopes have costae similar to those on the pedicle valve. The beak on this valve overhangs the hingeline about 1.8mm.

Valve interiors are unknown.

Discussion: Hall (1858) first described *A. opimus* as having rotund shells of nearly equal length and width, a highly arched umbo, and a strongly incurved beak. The sulcus contains three simple costae and the lateral flanks have 8-10. This description closely matches that of the Arrow Canyon specimens.

The Arrow Canyon specimens also closely resemble *A. rockymontanus* (Marcou), *A. mcalesteri* (Sutherland and Harlow), and *A. curvilateralis chavezae* (Sutherland and Harlow), but these species all have five costae in the sulcus. *A. occiduus* (Sadlick) and *A. matheri* (Dunbar and Condra) have more than five costae in the sulcus. *A. curvilateralis tanoensis* (Sutherland and Harlow) is similar in ventral view, but is much thinner, having a width that is slightly more than twice the thickness. *A. newberryi* (Sutherland and Harlow), has a much lower and less well developed fold and sulcus and *A. birdspringensis* has a greater width to length ratio.

Materials and Occurrence: There are two moderately good shells from VAL unit 144/145 (undifferentiated). Hypotype X6679 is complete, but slightly deformed, in contrast to hypotype X6680 which is incomplete and undeformed. Moffett (1986) reports this species in VAL units 158, 177, and 182B of Arrow Canyon which are above VAL unit 144/145. Huff (1984) identified the species in VAL unit 124.

Genus *Neospirifer* Fredericks, 1919
Neospirifer alatus Dunbar and Condra, 1932
Figs. 28-30

Neospirifer triplicatus var. *alatus* Dunbar and Condra, 1932, p. 332, pl. 38, figs. 11-12.

Neospirifer alatus Dunbar and Condra, 1932, p. 336, pl. 40, figs. 1-5; *alatus* Spencer, 1967, p. 26-28, fig. 18; *Neospirifer alatus alatus* Sutherland and Harlow, 1973, p. 75-76, pl. 17, figs. 1-5; Moffett, 1986, p. 106-108, pl. 17, figs. 3-5.

Description: The very large shells average about 75mm wide, 45mm long, and 22mm thick. The shells are alate and are widest at the hingeline. The pedicle valve is convex in both directions, but flattens close to the anterior margin.

The sulcus is moderately deep and contains 11 costae. These costae, which are poorly preserved, include: a median costa, four costae arising from the primary costae on each side, and two more arising from the two costae adjacent to the median. The lateral slopes bear 25-28 costae that show slight fasciculation which is more noticeable near the beak.

One brachial valve is available for study but it is deformed, obscuring any detail. No interiors were collected.

Discussion: Sutherland and Harlow (1973) synonymized Dunbar and Condra's (1932) *N. triplicatus* var. *alatus* and *N. alatus* in *N. alatus*, concluding that the two taxa actually were different growth stages of the same species.

The Arrow Canyon specimens are much larger and more obviously fasciculate than *N. cameratus* (Morton), *N. dunbari* (King), and *N. tewaensis* (Sutherland and Harlow). Dimensions of the Arrow Canyon specimens closely match those reported by Spencer (1967) and Moffett (1986) for *N. alatus*. Their specimens averaged 81mm wide, 46mm long, and 21mm thick.

Spencer (1967) defined species of *Neospirifer* by the bifurcation pattern on the fold or sulcus. By his rigid definitions, the specimens in question more closely match the patterns of *N. cameratus* than of *N. alatus*. Sutherland and Harlow (1973), however, do not use, or even mention, Spencer's (1967) identification system, but describe several different bifurcation patterns for each species. They recognize 8 different patterns in *N. alatus*, the most common of which closely resembles that of the Arrow Canyon specimens.

Materials and Occurrence: Several disarticulated pedicle valves were found in VAL units 136 and 139/140/141 (undifferentiated), only one of which (hypotype X6681) has moderately well preserved costae. Hypotype X6682 is a deformed brachial valve. Moffett (1986) reports *N. alatus* in the Upper Desmoinesian at Arrow Canyon. Sutherland and Harlow (1973) and Dunbar and Condra (1932) both report Missourian occurrences and Spencer (1967) documents a Virgilian occurrence.

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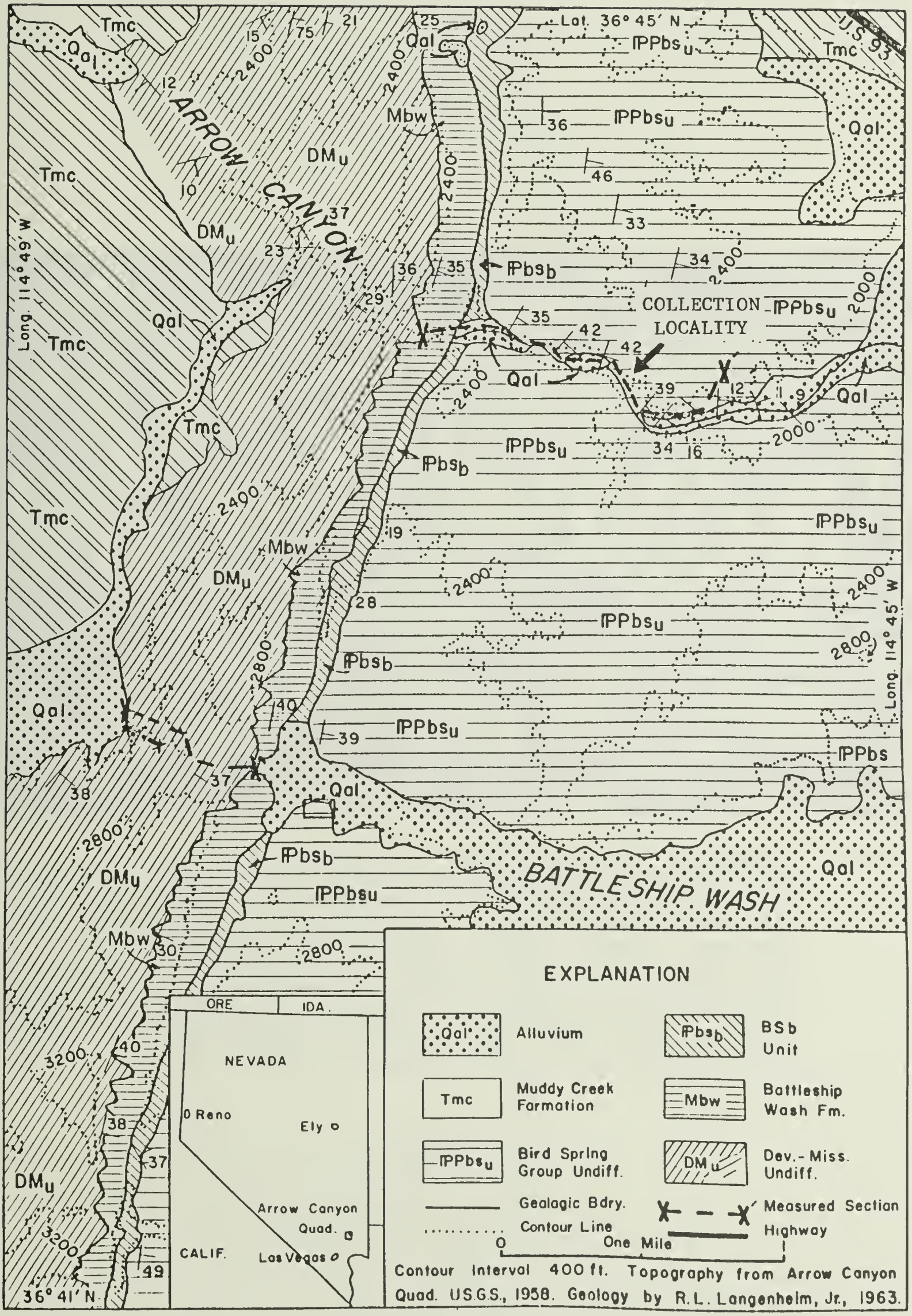

Figure 1. Location map of Arrow Canyon.

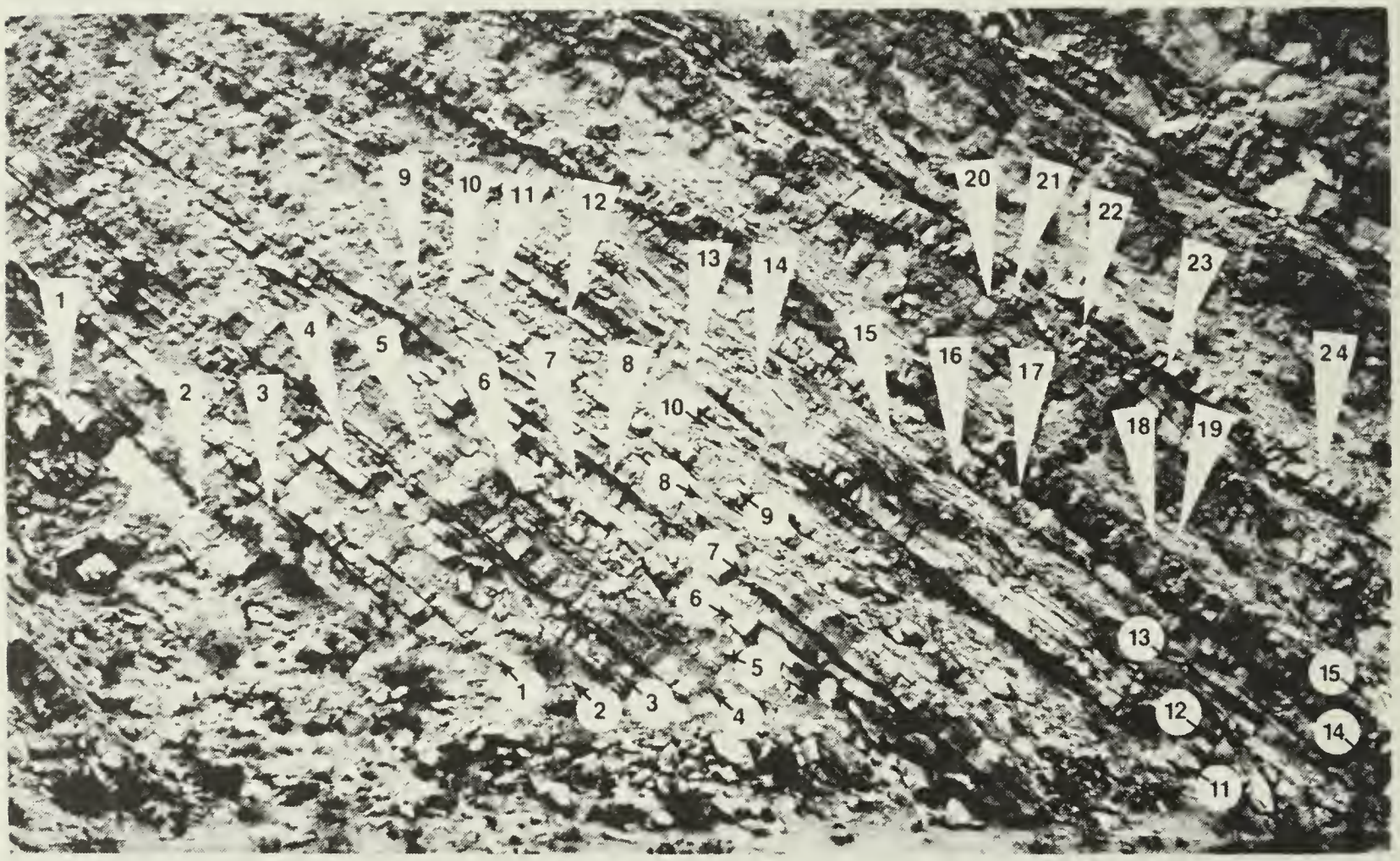

Figure 2. Photograph of section. *Unit Boundaries*° with *(Surveyed Reference Marks*°°*)*: 1. VAL 123A/123B (1-A276); 2. VAL 123B/124 (2-A277); 3. VAL 124/125 (3-A278); 4. VAL 127/128 (4-A279); 5. VAL 129/130 (5-A280); 6. VAL 130/131 (6-A281); 7. VAL 131/132 (7-A282); 8. VAL 132/133 (8-A283); 9. VAL 133/134 (9-A284); 10. VAL 134/135 (10-A285). Atokan/ Desmoinesian Boundary (Webster, 1969): 11. VAL 135/136A (11-A286); 12. VAL 136A/136B (12-A287); 13. VAL 136B/137 (13-A288); 14. VAL 137/138 (14-A289); 15. VAL 138/139 (15-A290); 16. VAL 140/141; 17. VAL 141/142; 18. VAL 142/143; 19. VAL 143/144; 20. VAL 144/145; 21. VAL 145/146; 22. VAL 146/147; 23. VAL 147/148; 24. VAL 148/149. After Plate 41, Weibel (1982). ° boundaries between units marked by wedges. °° markings placed at 1.5m intervals by AMOCO geologists, marked by dots.

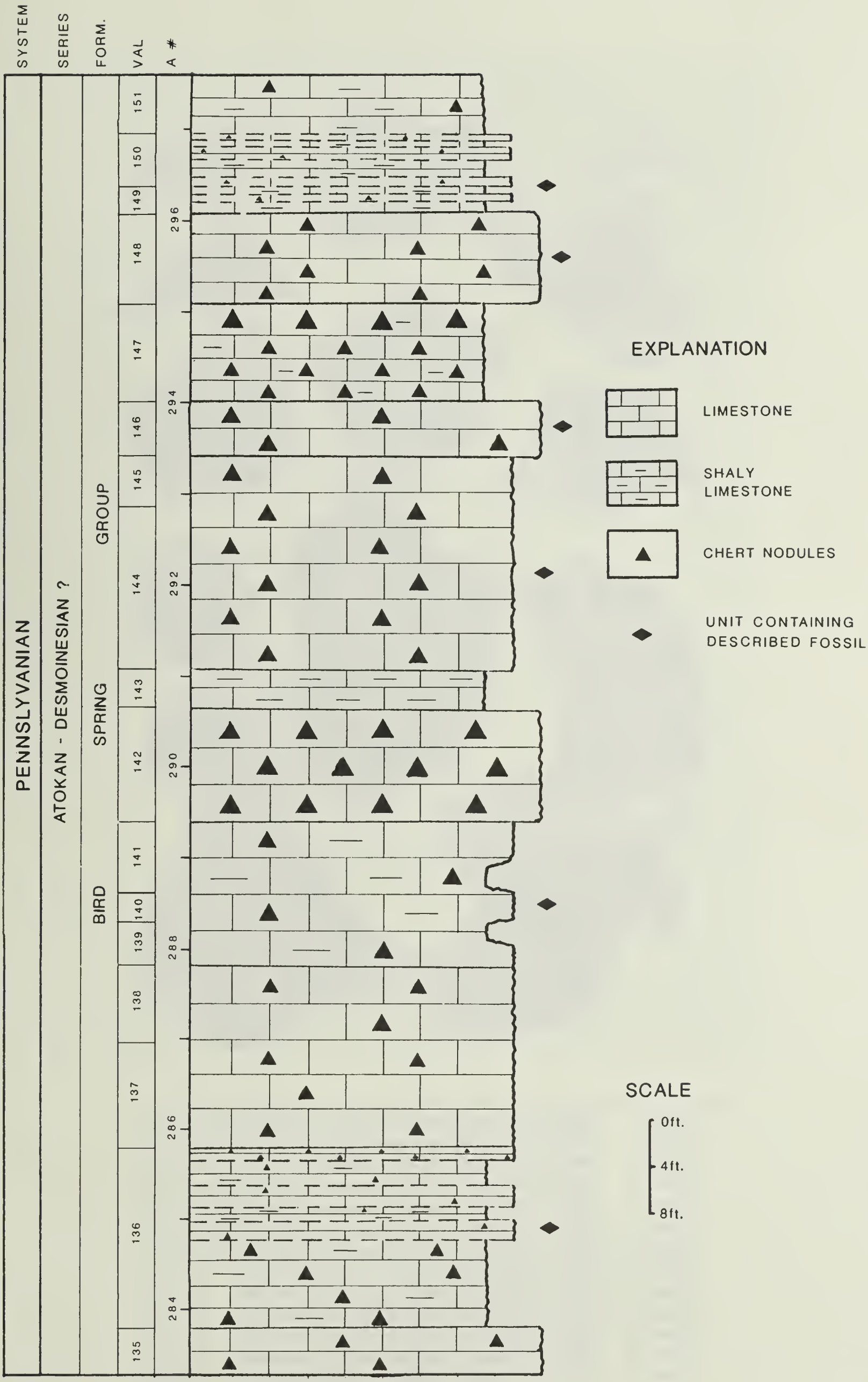

Figure 3. Stratigraphic column.

Figure 4. X6668 *Antiquatonia hermosana* pedicle interior
Figure 5. X6668 *Antiquatonia hermosana* pedicle exterior
Figure 6. X6668 *Antiquatonia hermosana* lateral view
Figure 7. X6668 *Antiquatonia hermosana* posterior view
Figure 8. X6669 *Antiquatonia hermosana* posterior view
Figure 9. X6669 *Antiquatonia hermosana* pedicle exterior
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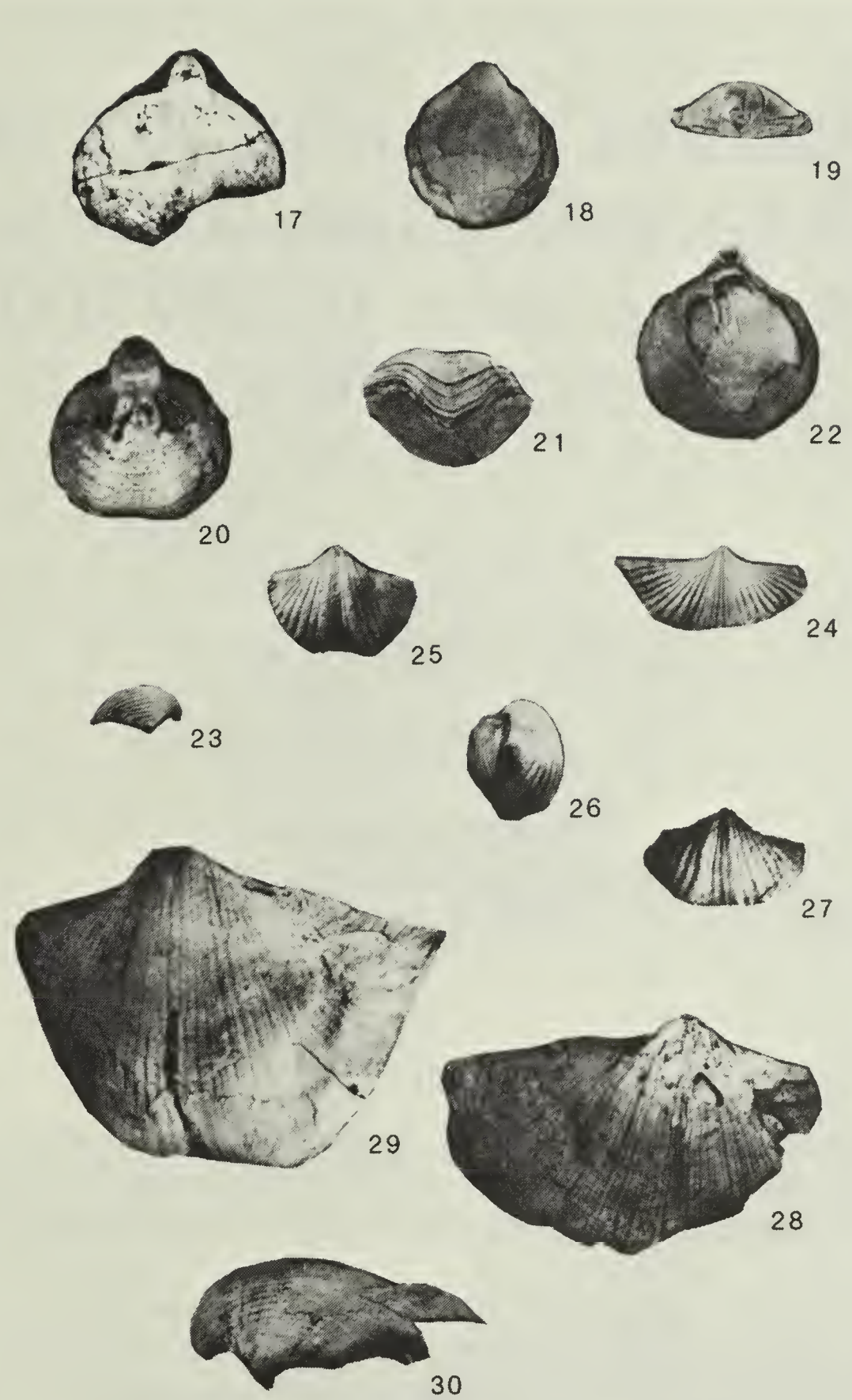

Figure 17. X6675 *Composita ovata* pedicle interior (internal mold)
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LECTIN BINDING AFFINITY IN NORMAL SKIN AND BENIGN, PREMALIGNANT AND MALIGNANT CUTANEOUS LESIONS

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ABSTRACT

The binding sites and affinities of the plant lectins concanavalin A (Con A) and Ricinus Communis Agglutinin (RCA-I) using the avidin-biotin-peroxidase complex (ABC) technique were studied in normal skin, benign, premalignant, and malignant epithelial skin tumors.

The reaction patterns of Con A and RCA-I are similar. The binding sites are located on epithelial cell membranes. The binding affinity increases with cellular differentiation. In normal skin, the binding affinity increases with epithelial maturation, the strongest reactivity occurring within the stratum granulosum. The basaloid cells of seborrheic keratosis are mildly reactive. In actinic keratosis, the reactivity is present in areas of dyskeratosis, but is absent in atypical rete ridges. Bowen's disease and basal cell carcinoma lack reactivity. The reaction pattern of squamous cell carcinoma is variable, increasing proportionately with squamous differentiation.

Lectin binding affinity is a marker of cellular maturation, increasing proportionately with squamous differentiation. The basaloid cells of normal skin and benign basaloid skin tumors have a weak binding affinity which is lost in dedifferentiating premalignant and malignant basaloid skin tumors.

INTRODUCTION

Lectins are glycoproteins with binding affinity for specific carbohydrates. Concanavalin A (Con A) is specific for B-D-mannose, and Ricinus Communis Agglutinin (RCA-I) is specific for β-D-galactose (1).

Carbohydrates are a dynamic part of cell membranes which change with cellular differentiation, maturation, and neoplastic transformation. Several studies have shown an increased binding affinity of lectins in neoplastic cells.

Our study demonstrates that lectin binding affinity varies proportionately with epithelial maturation and squamous differentiation. We speculate that this correlates with increasing concentrations of specific oligosaccharides produced in maturing squamous cell membranes. Therefore, lectin binding affinity can be used as a marker to demonstrate squamous differentiation in epithelial skin tumors.

We have studied the binding sites and affinities of Con A and RCA-I in 5 normal skin controls, 7 seborrheic keratosis, 4 actinic keratosis, 6 Bowen's disease, 9 squamous cell carcinoma, and 5 basal cell carcinomas.

MATERIALS AND METHODS

Blocks of paraffin-embedded tissues were sectioned at 3 μm. After deparaffinization, sections were treated with 0.075% HC1 in absolute ethanol to supress endogenous peroxidase activity (2). Sections were treated with a solution of biotinylated lectin (Vector, Burlingame, CA), 10% bovine serum albumin (3) and 0.05 M Tris-buffered saline, pH 7.6 (room temperature) for 30 minutes. Concentrations of biotinylated lectins were: Con A, 10 μg/ml; RCA 50 μg/ml. The Con A solution contained 1 mM $MnCl_2$. Negative controls were produced by addition of 1% of the respective specific monosaccharides to the lectin solutions. This was followed by treatment for 60 minutes with avidin-biotin-peroxidase complex (Vector). It was prepared 30 minutes before use according to the manufacturer's instructions in tris-buffered saline with 0.2% albumin. All steps were followed by washing in Tris-buffered saline. The peroxidase label was visualized by addition of 0.04% diaminobenzidine hydrochloride in ammonium acetate-citrate buffer containing 0.0075% H_2O_2, for 2.5 minutes at pH 5.5 (4). After thorough washing in water, sections were counterstained with hematoxylin and mounted in Permount.

RESULTS AND DISCUSSION

A positive reaction was evidenced by a brownish color on cellular membranes visualized by light microscopy. The staining intensities were graded as negative, mildly, moderately and strongly reactive. Both Con A and RCA showed the same binding patterns. In normal skin, the basal layer was negative to mildly positive. The staining intensity progressively increased with cell maturation, the strongest reaction occurring within the stratum granulosum (Fig. 1). A similar pattern was observed in the follicular epithelium. Sebaceous glands were strongly positive. The acinar epithelium of eccrine glands was negative with a moderate staining reaction in eccrine ductal epithelium.

In seborrheic keratosis, the areas of basaloid acanthosis showed mild reactivity with both Con A and RCA-I. The pseudohorn cysts were moderately positive (Fig.

2). The dyskeratotic cells of actinic keratosis were moderately to strongly reactive; the atypical basaloid cells within the rete ridges were negative to mildly positive (Fig. 3).

Bowen's disease showed a complete lack of reactivity throughout the entire epidermal thickness. In cases with areas of parakeratosis, a moderate reactivity was observed.

In basal cell carcinoma, the basaloid nests were completely negative for RCA but focally positive with Con A. Areas with evidence of squamous or follicular differentiation were moderately to strongly reactive with both Con A and RCA-I (Fig. 4).

Variable staining patterns occurred within infiltrating squamous cell carcinoma which correspond to cellular maturation. In poorly differentiated areas, the reaction was negative to mildly positive, while a strong reaction pattern was observed in dyskeratotic cells and keratin pearls.

Selective binding of lectins to cellular components is determined by the presence of oligosaccharides specific to each lectin. Concanavalin A (Con A) binds specifically to α-D-mannose or α-D-glucose; Ricinus Communis Agglutinin (RCA-I) binds specifically to β-D-galactose.

Epithelial binding of Con A has been investigated more extensively than other lectins. Most of the reports demonstrate a significant increase in its affinity to a wide range of epithelial tumors including carcinoma of skin and melanoma (6), gastric carcinoma (7), endometrial carcinoma (8), and cervical carcinoma (9). However, most of the information concerning human tissues has been derived from the study of formalin fixed paraffin embedded tissue sections (8, 5, 10). These sections show a reduced staining reactivity as compared with frozen section tissue (11).

Our study strongly demonstrates that an increase in staining intensity for lectins by the avidin-biotin-peroxidase complex method in normal skin as well as skin tumors corresponds to the degree of cellular differentiation and probably to the presence of keratohyalin granules, keratinization, and increase in specific oligosaccharides in epithelial membranes.

We conclude that lectin binding affinity in normal skin corresponds to epithelial maturation with the strongest affinity occurring within the stratum granulosum. With epidermal dysplasia and lack of cellular maturation (as in Bowen's disease, actinic keratosis and basal cell carcinoma), the lectin binding affinity is lost. However, in infiltrating squamous cell carcinomas, lectin binding affinity increases with squamous differentiation.

The basaloid areas of seborrheic keratosis show mild to moderate staining reactions which corresponds to proliferation of the maturing cells of the stratum spinosum.

While lectin binding affinity cannot be used as a marker for epithelial tumor identification, it can be used to demonstrate cellular maturation and squamous differentiation within skin tumors, and to better assess areas of epithelial dysplasia in skin biopsy specimens.

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Figure 1. Normal skin: marked reaction for RCA-I in stratum granulosum (Avidin-biotin-peroxidase complex, X 140).

Figure 2. Seborrheic keratosis: mild to moderate reaction in basaloid areas (RCA-I, Avidin-biotin-peroxidase complex, X 140).

Figure 3. Actinic keratosis: lack of positive reaction in atypical areas; positive reaction in dyskeratotic cells (arrows). (Con A, Avidin-biotin-peroxidase complex, X 140).

Figure 4. Basal cell carcinoma: lack of reaction in basaloid nests (Con A, Avidin-biotin-peroxidase complex, X 140).

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EFFECTIVENESS OF SELECTED LEAD AND STEEL SHOT SHELLS FOR DISPATCHING CRIPPLED DUCKS

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ABSTRACT

The effectiveness of 7 different shot charges in 2¾-inch, 12-gauge shells in dispatching crippled ducks was evaluated in Illinois in 1978-1983. Hunters fired a total of 2,969 shells (mean distance 31 m) at 1,795 ducks. Dispatching rates for crippled ducks were 90-94% for steel #5, copper-coated lead #7½, and lead #8; 87% for lead #6 and steel #4; and 82-84% for lead #4 and steel #6. Collectively, the 3 steel shot loads were similar to the 4 lead shot loads in effectiveness for dispatching crippled ducks.

INTRODUCTION

Crippled birds — those hit with a charge of shot but not retrieved — are an undesirable aspect of waterfowl hunting, especially because relatively few recuperate in the wild (Bellrose 1953, Van Dyke 1981, Kirby et al. 1981). Crippling rates averaged 16.9% of all ducks knocked down (20.3 birds per 100 bagged) in the United States during the 1971-1984 hunting seasons (U.S. Fish and Wildlife Service, Office of Migratory Bird Management, Admin. Rep. 1973-1985). Factors that influence crippling rates include species of waterfowl, type of habitat, use of a dog, competition among hunters, and the skill of the individual hunter (Bellrose 1953:338).

If hunters do not quickly dispatch (kill or incapacitate) crippled ducks that have been knocked down over aquatic habitats, cripples elude being reduced to possession by diving, hiding, and/or swimming away. In a survey of some 1,500 duck hunters in Illinois during the 1979 season (when lead shot accounted for 97% of the state's duck harvest), 79% used 2¾- or 3-inch, 12-gauge shells; 79% used unbuffered shot charges; and 97% used #6 or larger shot (49% used #4 and 26% used #6) (W. L. Anderson, unpublished data). However, 24% of all hunters surveyed used small shot (#9, #8, #7½) for dispatching cripples. These hunters believe that a charge of many small shot places more pellets in vital areas (head or neck) than conventional duck loads.

The mandatory use of nontoxic (steel) shot for waterfowl hunting on selected areas began in the Atlantic Flyway in 1976, in the Mississippi Flyway in 1977, and in the Central and Pacific flyways in 1978. Nontoxic shot will be required for all waterfowl hunting in the United States beginning in 1991 (U.S. Dep. Inter. 1986). Decisions regarding the seriousness of lead poisoning in waterfowl and whether to convert to nontoxic shot have not been made in Canada, Mexico, most of Europe, and elsewhere. Thus, this study was undertaken to evaluate the effectiveness of small shot sizes relative to large shot sizes and of steel shot relative to lead shot in dispatching crippled ducks in aquatic habitats. The ultimate goal is to reduce crippling losses associated with duck hunting.

METHODS AND MATERIALS

Twelve-gauge, 2¾-inch shotgun shells loaded with 7 different shot charges were used: 1⅛-oz lead #8 (Remington ShurShot), 1¼-oz copper-coated lead #7½ (Federal Premium), 1¼-oz lead #6 (Remington Express), 1¼-oz lead #4 (Winchester Super-X), 1⅛-oz steel #6 (Federal Hi-Power), 1⅛-oz steel #5 (Federal Hi-Power), and 1⅛-oz steel #4 (Remington Waterfowl). None of the shells was buffered. The copper-coated lead #7½, lead #6, and lead #4 shells were purchased from local retail dealers; the other shells were purchased directly from the manufacturers. Ballistic characteristics and patterning performances of these shells are summarized in Table 1.

For the most part, each of the 7 types of shells was tested during 2 consecutive years during the 6-year period, 1978-1983. Testing was conducted on public and private areas throughout Illinois by duck hunters from the Illinois Department of Conservation, the Illinois Natural History Survey, and private citizens. A diversity of habitats that varied from open "big" water to vegetation-choked marshes were represented.

Potential participants were contacted in September of each year to determine (1) whether they were willing to use the test shells (provided free) and to record data while duck hunting and (2) how many shells of each type they could reasonably use in 1 season. Participants were subsequently sent 10-25 shotgun shells of each type they had specified (78% were issued $\geq$2 types), standardized forms on which to record data, and printed instructions. The instructions stipulated that the test shells were to be used in the same manner as other shotgun shells for dispatching crippled ducks. Data were recorded by the hunters (a separate form for each bird) for species, number of shells fired, estimated distance (in yards) for each shell, and

whether the ducks were successfully dispatched. The criteria for comparing the effectiveness of shells were (1) percentage dispatched of crippled ducks shot at and (2) number of ducks dispatched per 100 shells of each type fired.

The data were analyzed with computer facilities at the University of Illinois, Champaign. Differences among the shell types were tested for significance using the arcsine test (Sokal and Rohlf 1969:607).

RESULTS

During the 6-year study, 173 individual hunters (mean of 64 per year) were issued 15,685 shotgun shells: 1,360 lead #8, 3,040 copper-coated lead #7½, 2,605 lead #6, 2,130 lead #4, 2,125 steel #6, 2,250 steel #5, and 2,175 steel #4. Of the hunters, 116 (67%) generated usable data by firing 2,969 shells at 1,795 ducks. Mean distance to the ducks, as estimated by the hunters, was 31.0 ± 0.3 (SE) m. The ducks were 49% mallards (*Anas platyrhynchos*) and black ducks (*A. rubripes*), 28% other dabbling ducks (*Anas* spp. and *Aix sponsa*), 21% diving ducks (primarily *Aythya* spp. and *Bucephala* spp.), and 2% unidentified.

The percentage dispatched of crippled ducks shot at was highest for steel #5, copper-coated lead #7½, and lead #8, intermediate for lead #6 and steel #4, and lowest for lead #4 and steel #6 (Table 2). Except for lead #8 versus lead #4 and steel #4, all differences between the 3 highest and the 3 lowest percentages were significant ($P < 0.05$).

For the number of ducks dispatched per 100 shells fired, the steel #5, copper-coated lead #7½, and lead #8 exhibited the highest values, lead #6 and steel #4 were intermediate, and steel #6 and lead #4 had the lowest values (Table 2). Except for lead #8 versus steel #4, all differences between the 3 highest and the 3 lowest values were significant ($P < 0.05$).

DISCUSSION

This study was designed to test the relative effectiveness of 7 different shot charges in 2¾-inch, 12-gauge shells in dispatching crippled ducks. We did not, however, take into consideration crippled birds that were not searched for or dispatching attempts in which no shells were fired. Thus, our findings are not representative of retrieval rates for all ducks knocked down in aquatic habitats.

In addition, we did not have rigid control over the collection of data, as was the case in recent field tests of steel versus lead shot for waterfowl hunting (Mikula et al. 1977, Anderson and Sanderson 1979, Humburg et al. 1982, Hebert et al. 1984). In those tests, evaluation of the effectiveness of shotgun shells was complicated by the fact that the targets were frequently multiple and always in flight. According to Humburg et al. (1982:124), who worked in Missouri, data recorded by duck hunters was, on average, within 14% of data recorded by trained observers. In this test, hunters' versus observers' estimates of distances to ducks were similar at 27-37 m, significantly greater at < 27 m, and significantly less at >37 m (Humburg et al. 1982:124). In comparison, the process was simplified in our study — i.e., hunters attempted to hit single birds that were stationary or moving slowly on water. The hunters recorded the number of shells fired per attempt (67% involved 1 or 2 shells),

whether the duck was dispatched, and estimated distances to the duck, the mean of which was 31.0 ± 0.3 (SE) m. Although our methods were something less than scientifically perfect, we submit that they produced useful data for attempting to reduce crippling losses associated with duck hunting.

Of the 7 types of shells tested, steel #5, copper-coated lead #7½, and lead #8 were the most effective in terms of the percentage of crippled ducks dispatched (Table 2). In terms of ducks dispatched per 100 shells fired, the steel #5, copper-coated lead #7½, and lead #8 also exhibited the best performances.

In countries where lead shot is permitted for waterfowl hunting, duck hunters should be encouraged to use shotgun shells loaded with small-size shot such as lead #7½ and lead #8 for dispatching cripples. These loads of small shot were more effective than the common duck loads consisting of lead #4 or #6 shot (Table 2). Indeed, significant ($P<0.05$) positive correlations existed between the dispatching rates for crippled ducks that were shot at and the number of pellets in the pattern (Table 1) for the 4 lead shot loads: $r = 0.98$ (df = 2) at 27.4 m and $r = 0.96$ (df = 2) at 36.6 m. Thus, the lead shot loads can be ranked in order of effectiveness for dispatching crippled ducks: copper-coated lead #7½, lead #8, lead #6, and lead #4.

In countries where nontoxic shot is required, steel #5 shot is recommended for dispatching crippled ducks. This load was more effective than either the steel #6 or steel #4 shells (Table 2). Unlike the lead loads, no relationship was found between the number of pellets in the pattern and the effectiveness of the 3 steel shot shells for dispatching cripples. Compared with the 2 other steel shot loads, the steel #6 placed the most pellets in the 30-inch circle (Table 1) but was least effective for dispatching crippled ducks (Table 2). Because we cannot explain this apparent "anomaly" in the performance of the 3 steel shot shells, additional testing of various sizes of steel shot may be warranted. In the interim, the steel shot loads are ranked in order of effectiveness as follows: steel #5, steel #4, and steel #6.

For purposes of comparing lead versus steel shot for dispatching crippled ducks, data for the 4 lead shot loads may be combined in 1 group and data for the 3 steel shot loads in another. Dispatching rates for crippled ducks were 88.7% for lead loads and 88.0% for steel loads. Similarly, the number of cripples dispatched per 100 shells fired was 52.8 for the lead loads and 54.1 for the steel loads. These small differences between the lead and steel loads were not significant ($P>0.05$), and we conclude that taken collectively effectiveness of the 3 steel shot loads was similar to that of the 4 lead shot loads.

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Ill. Nat. History Survey, and U.S. Fish and Wildl. Serv., cooperating. The U.S. Fish and Wildl. Serv. has no responsibility for the form and content of the data in this report or for the conclusions reached.

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Table 1. Ballistic characteristics and patterning performance of 2¾-inch, 12-gauge shells tested for effectiveness in dispatching crippled ducks in aquatic habitats in Illinois, 1978-1983 hunting seasons.

Type and Size of Shot	Nominal Shot Charge (oz)	Pellets per Shell[b]	Nominal Velocity (fps)[c]	Number of Pellets in Pattern[a]	
				27.4 m (30 yards)	36.6 m (40 yards)
Lead #8(.090)[d]	1⅛	449	1,255	390 (86.9)[e]	241 (53.8)[e]
Lead #7½[f] (.095)	1¼	451	1,220	422 (93.6)	339 (75.2)
Lead #6 (.110)	1¼	286	1,330	234 (81.8)	159 (55.6)
Lead #4 (.130)	1¼	168	1,330	154 (91.7)	113 (67.3)
Steel #6 (.110)	1⅛	354	1,365	327 (92.4)	275 (77.7)
Steel #5 (.120)	1⅛	259	1,365	250 (96.5)	205 (79.2)
Steel #4 (.130)	1⅛	215	1,365	189 (87.9)	145 (67.4)

[a]Patterns were determined by firing 10 shells of each type at each distance and counting the number of pellets registering in a circle 30-inches in diameter drawn around the densest portion of the pattern. Pattern testing was conducted at Champaign, Illinois, in mean temperature of 22 C, at an elevation of 213 m, under no-wind conditions, and through a 30-inch full-choke barrel.

[b]Mean for 10 shells.

[c]Mean velocity (n=10) of each test shell was within current SAAMI (Sporting Arms and Ammunition Manufacturers' Institute) specifications, as tested by H.P. White Laboratory, Inc., Street, MD.

[d]Diameter in inches.

[e]Numbers within parentheses are percentages calculated by using the mean number of pellets registering inside the 30-inch circle divided by the mean number of pellets found in 10 shells of the type being tested.

[f]Copper-coated.

Table 2. Effectiveness of selected 2¾-inch, 12-gauge shells in dispatching crippled ducks in aquatic habitats in Illinois, 1978-1983 hunting seasons. Values followed by the same capital letters in the same column differ significantly ($P<0.05$).

Type and Size of Shot	Number of Shells Fired[a]	Crippled Ducks		
		Number Shot At	Percentage Dispatched	Number Dispatched per 100 Shells
Lead #8	253	160	90.0 A	56.9 AB
Lead #7½[b]	557	352	91.8 BCD	58.0 CDE
Lead #6	393	234	87.2 E	51.9 FG
Lead #4	379	197	83.8 BF	43.5 ACFHI
Steel #6	451	262	82.8 ACG	48.1 BDJ
Steel #5	440	289	93.8 EFGH	61.6 GHJK
Steel #4	496	301	87.0 DH	51.8 EIK

[a]Mean distance to the crippled ducks was 31.0 ±0.3 (SE) m (n = 2,329), as estimated by hunters who participated in the test.

[b]Copper-coated.

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NOTES ON THE ECOLOGY OF THE CENTRAL NEWT (NOTOPHTHALMUS VIRIDESCENS LOUISIANENSIS) IN SUBURBAN NORTHEASTERN ILLINOIS

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ABSTRACT

1. Terrestrial newts from a population in northeastern DuPage County occurred primarily in oak/hickory forest rather than old field habitat, and 75% were found beneath boards or other anthropogenic debris.

2. Newts were found in terrestrial habitats only during August and September. This may represent a shift from aquatic habitats, which often declined drastically in late summer.

3. In all years, newts were separated into two major length (age?) classes.

4. Analysis of fecal pellets indicated that snails were a major dietary component. Snails occurred in every fecal pellet. Larger newts ate larger snails but continued to eat small snails as well. Oribatid soil mites and other small arthropods were also consumed.

5. Longterm observations from the mid-1960's to the present suggest that this newt population is subject to large fluctuations in abundance.

INTRODUCTION

Terrestrial stages of the central newt (*Notophthalmus viridescens louisianensis*) were reported by Pope (1964) and Vogt (1981) to be uncommon in the upper

Midwest (but see Smith, 1961). Discovery of a population with terrestrial individuals in DuPage County, northeastern Illinois, permitted collection of the length-frequency, dietary, and habitat information reported herein. Since the population represents one of the very few extant populations of central newts in DuPage County, I also provide suggestions for its future management.

METHODS

All newts were collected during daytime searches in August and September, 1980-1985, in oak/hickory forest and old fields near a wooded, semi-permanent wetland (T-40-N, R-11-E, S-22). This study area and its herpetofauna are more thoroughly detailed by Cochran (in press). Searches through the same habitat in April (1980, 1981, 1984) and June (1985-1987) were unsuccessful (surveys were not attempted in May or July).

Because central newts are considered rare in DuPage County (Forest Preserve District of DuPage County, 1986), they were not sacrificed to collect gut contents. Rather, fecal pellets were collected by housing newts overnight in individual containers (except for one instance when 3 pellets were collected from 5 newts held together), and the newts were released at their sites of capture. Analysis of fecal pellets underestimates the importance of soft-bodied prey but can be used to demonstrate use of prey with hard parts resistant to digestion. Prey items were measured under a microscope with an ocular micrometer, and body length, defined here as the distance from the tip of the snout to the posterior edge of the insertion of the hind limbs, was measured for each newt to the nearest millimeter.

Voucher specimens were placed in the University of Wisconsin-Madison Zoology Museum (UWZM-H22588-9).

RESULTS

Forty-eight newts were collected on 11 dates from 1980-1985. Thirty-nine newts were found in oak/hickory forest; the remainder occurred in shrubby old field habitat (always near an ecotone with wooded habitat). Twelve newts (25%) were collected beneath logs, bark, or other natural objects, whereas 36 (75%) were found beneath boards or other anthropogenic debris. Substrates ranged from moist to dry; cover objects were often "cemented" to the ground by earthworm castings.

In all years, newt body length fell within two discrete classes. Between 1 August and 7 September, all but one newt were within body length ranges of 19-23 mm (n=18) or 28-39 mm (n=23); a single 45-mm specimen possibly represented a third size (age?) class. A single collection on 26 September 1980 included one 27-mm newt and four within a range of 38-42 mm.

A total of 26 fecal pellets from at least 15 newts (1-3 pellets/newt) were analyzed. Snail shells, usually entire, were found in every pellet. Sixty "spire"-shaped snails (shell length: 1.2-6.9 mm) were found in pellets from at least 11 newts, whereas 53 "wheel"-shaped snails (shell diameter: 0.7-6.6 mm) were found in 13 newts. Among newts that contained more than one snail of a given type, newt body length was correlated with the maximum length for spire shells ($r=0.678$, $n=7$, $P<0.10$) and maximum diameter for wheel shells ($r=0.709$, $n=11$, $P<0.05$) but not with minimum values ($r=0.358$ and $r=0.163$, respectively). This suggests that larger

newts were capable of eating larger snails while retaining smaller snails in their diet. Other prey items found in fecal pellets included 21 oribatid mites (in 7 newts), 2 ants (in 2 newts), 1 beetle, 4 unidentified insect larvae (in 2 newts), and miscellaneous arthropod fragments (in 5 newts).

DISCUSSION

The smallest newts collected during this study probably represent efts recently transformed from the aquatic larval stage. I do not know whether larger newts represent older efts or adult newts that have shifted from the normal aquatic adult phase. I never collected terrestrial newts in the study area earlier than August. Since the wetland at the center of the study area in some years dries completely, or nearly so, in late summer, the newt population may shift between aquatic and terrestrial habitats in midsummer. Premo (1982) described a similar shift by a newt population in Michigan, although the shift was not associated with dessication of their aquatic habitat (see also Hurlbert 1969 and references therein).

Some evidence suggests that this newt population is subject to large fluctuations in abundance. During the period 1964-1975, when I lived at the edge of the study area and actively searched for reptiles and amphibians, I observed fewer than 5 newts (including 2 on 17 August 1969). During 1980-1983, as many as 11 individuals could be collected within a two-hour period. Only one individual was collected in 1985, and none on 9 October 1986. On 16 September 1987, 12 newts were collected in a wooded wetland north of the study area (Redmer, personal communication, 21 September 1987).

Snails were by far the most important prey item discovered in the fecal pellets; oribatid mites were a distant second. According to Drewes and Roth (1981), few vertebrates feed on snails, and few terrestrial vertebrates feed on snails without crushing the shells or removing and eating only the soft parts. For newts, consumption of snails (see also Smith, 1961 and Burton, 1976) may provide for dietary continuity between aquatic and terrestrial phases, since at least some Illinois populations rely heavily on snails as larvae (Brophy, 1980). The importance of soil mites in the diets of New York newts was discussed by Norton and MacNamara (1976).

Newts have declined in abundance in Illinois during historical times (Smith, 1961). In northeastern Illinois, Smith (1961) reported newts from northeastern DuPage County in the general vicinity of the present study area, and both he and Pope (1964) reported newts from Cook and Lake Counties. A specimen in the collection of the Illinois Natural History Survey (INHS 2303) was collected on 14 October 1942 in "Cook Co., Bensenville," (Larry M. Page, personal communication, 17 October 1980), whereas a specimen in the Field Museum of Natural History (FMNH 35761) was collected in Wooddale, DuPage County, probably prior to 1945 (Harold K. Voris, personal communication, 28 November 1980). More recently, newts have been reported from Cook County by Jessup (1981) and were listed for Cook, Lake, and Will Counties by Pentecost and Vogt (1976). The Forest Preserve District of DuPage County (1986) has recorded newts from three localities, including the present study area, since 1980.

The effects of humans on the herpetofauna of northeastern Illinois are varied. Most obvious is the obliteration of habitat by commercial, agricultural, and residential development. During my extended association with the study area, portions at

its periphery were converted to homes (Cochran, in press). Another impact, especially near residential areas, results from children who collect and move reptiles and amphibians (see Hurlbert 1969, p. 479), keep them for pets, or kill them outright. I was aware of one individual who collected and removed salamanders (including at least one newt) from the study area during the 1960's. A potential beneficial impact of humans in the study area results from the accumulation of anthropogenic debris, which provided cover for 75% of the newts collected during this study. Most of this debris resulted from two activities: (1) dumping of garden and other trash, usually in ecotones between field and woods, and (2) construction and abandonment of clubhouses by children. The latter activity resulted in two accumulations of boards that eventually served as cover for newts.

Much of the habitat used by newts during the present study has been recently acquired by the Forest Preserve District of DuPage County, although part of the wetland was not included in the acquisition and has been diminished by dumping of fill along part of its shoreline. Unfortunately, construction of a trail obliterated an accumulation of boards that accounted for the largest number of newt collections during this study. Although removal of anthropogenic debris is an understandable action following designation of an area as a natural preserve, such debris may serve as important cover for some species of reptiles and amphibians and may offer a way of monitoring abundance of species less easily collected in natural refuges. Management for newts in the study area should include placement of debris piles for use as shelter sites. These piles should preferably be placed in wooded habitat near the wetland where they will be shaded. Any such piles should not be separated from the wetland by intervening trails or roads and should be screened from casual observers by appropriate plantings.

Longterm management for newts in the study area may require efforts to offset obliteration of the wetland. Succession and encroachment by purple loosestrife (*Lythrum salicaria*) are reducing its surface area and depth. However, any deepening or enlargement of the wetland should not be followed by stocking of fish, a common practice in suburban forest preserves (and already scheduled for a borrow pit just south of the study site). Addition of fish to aquatic communities is often followed by loss of amphibian species, including *Notophthalmus viridescens* (Sexton and Philips, 1986).

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FALCAUSTRA CATESBEIANAE WALTON, 1929 (NEMATODA: KATHLANIIDAE) IN THE SMALLMOUTH SALAMANDER, AMBYSTOMA TEXANUM (MATTHES, 1855) (CAUDATA: AMBYSTOMATIDAE) FROM ILLINOIS

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ABSTRACT

Falcaustra catesbeianae was detected in 1 of 5 *Ambystoma texanum* examined from southern Illinois. This constitutes the third report of this nematode in a caudate amphibian and the first in *Ambystoma texanum*.

INTRODUCTION

The geographic range of the smallmouth salamander, *Ambystoma texanum* (Matthes, 1855) extends from extreme southeastern Michigan and Pelee Island Ontario, west to southern Iowa and south to the Gulf coast of Texas, Louisiana, and Mississippi (Anderson, 1967). While a few surveys on the endoparasites of *A. texanum* have been conducted, reports on their nematode fauna are indeed scarce. Perhaps this may be due in part to their nocturnal and fossorial habits which limits the collection of large numbers of specimens to breeding periods in late February throughout March (Price and St. John, 1980). Only two nematodes, namely, *Cosmocercoides dukae* (Holl, 1828) and *Rhabdias* sp. have thus far been reported in *A.*

texanum. Harwood (1932) reported *C. dukae* in 1 of 4 *A. microstomum* (= *A. texanum*) from southern Texas. In an unpublished thesis, Landewe (1963) recorded *C. dukae* and *Rhabdias* sp. in 61 *A. texanum* examined from southern Illinois. Price and St. John (1980) examined 57 *A. texanum* from Williamson County, Illinois and reported 5% infected with *C. dukae* and 72 and 77% infected with larval and adult *Rhabdias* sp., respectively. This report is based on a collection of nematodes heretofore not reported from *A. texanum*

MATERIALS AND METHODS

Five *Ambystoma texanum* collected in Jackson County, Illinois during March 1987 were examined for helminths. Nematodes detected in the large intestine of one smallmouth salamander were fixed in hot glycerin-alcohol (nine parts 70% ethanol and one part glycerin) and cleared for study in glycerin. Representative specimens have been deposited in the Helminthological Collection of the Zoological Museum, Southern Illinois University at Carbondale, No. 120A.0.

RESULTS AND DISCUSSION

Falcaustra catesbeianae Walton, 1929 has been recorded in several anuran amphibians from North America. Walton (1929) described *F. catesbeianae* from *Rana catesbeiana* and listed the geographic range of this nematode as Illinois, Oklahoma and Louisiana. In a preliminary study of the parasitic fauna of Oklahoma anurans, Trowbridge and Hefley (1933) found 6 of 21 *R. catesbeiana* and 1 of 38 *R. sphenocephala* infected with *F. catesbeianae*. Later, Walton (1938) listed *Gastrophyrne carolinensis, Hyla gratiosa, H. cinerea, Limnaoedus ocularis, Rana grylio, R. sphenocephala* and *Siren lacertina* as hosts of *F. catesbeianae* from Florida. Reiber et al. (1940) recovered about two dozen specimens of *F. catesbeianae* from *R. catesbeiana* from Athens, Georgia. Kunts and Self (1943) reported 139 of 226 *R. catesbeiana* from Comanche County, Oklahoma to be infected with *F. catesbeianae*. Ashton and Rabalais (1978) found 5 (20.8%) of 24 *R. catesbeiana* from northwestern Ohio infected with *F. catesbeianae*. Recently, Baker (1986) reported *F. catesbeianae* in *R. catesbeiana* from southern Ontario.

Dyer (1975) found 1 (0.8%) of 119 grotto salamanders, *Typhlotriton spelaeus* Stejneger, 1893 collected from Wet Cave, Shannon County, Missouri infected with *F. catesbeianae*. This plus the above report for *Siren lactertina* are the only two reports of caudate amphibian hosts for *F. catesbeianae* known to me.

Previous studies on the helminths of *A. texanum* in Illinois have failed to detect *F. catesbeianae*. This nematode was neither found by Landewe (1963) who examined 61 *A. texanum* from Jackson, Alexander and Union Counties nor by Price and St. John (1980) who examined 57 *A. texanum* from Williamson County. The finding of *F. catesbeianae* in 1 of 5 *A. texanum* in the present study constitutes a third report of this nematode in a caudate amphibian and the first in *A. texanum*.

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HEDRURIS SIREDONIS BAIRD, 1858 (NEMATODA: HABRONEMATOIDEA) FROM AMBYSTOMA SP. (AMPHIBIA: AMBYSTOMATIDAE) OF LAGUNA QUECHOLAC, PUEBLA, MEXICO

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ABSTRACT

Of eighty-five *Ambystoma sp.* collected from Laguna Atexcac, Laguna Quecholac, and Laguna de la Mina Preciosa, Puebla, Mexico, three from Laguna Quecholac were infected with *Hedruris siredonis* Baird, 1858.

INTRODUCTION

Hedruris Nitzsch, 1821, the only genus of the habronematid family Hedruridae, comprises 24 nominal species distributed throughout the world in frogs, salamanders, freshwater turtles, lizards, and freshwater and marine fish (Baker, 1982). In a comparative morphological study of the five *Hedruris* described from North America, Baker (1986) concluded that the only valid two species are *H. pendula* (Leidy, 1851) Chandler, 1919 parasitic mainly in freshwater turtles of eastern North America and *H. siredonis* Baird, 1858 reported only from salamanders (Ambystomatidae, Salamandridae, Plethodontidae) throughout North America. Thus, *Hedruris tiara* Van Cleave and Mueller, 1932 was synonymized with *H. pendula*, whereas *H. brevis* Walton, 1930 and *H. chandleri* Freitas and Lent, 1941 were synonymized with *H. siredonis*. In a later report, Muzzall and Baker (1987)

reported *H. siredonis* from green frogs, *Rana clamitans* and bullfrogs, *R. catesbeiana* of New Hampshire. This constituted the first report of *H. siredonis* in North American frogs. The present report is concerned with *H. siredonis* recovered from *Ambystoma* sp. of Laguna Quecholac, Puebla, Mexico.

MATERIALS AND METHODS

Eighty-five *Ambystoma* sp. collected from Laguna Atexcac, Laguna Quecholac, and Laguna de la Mina Preciosa, Puebla, Mexico during July 1981 were examined for helminths. Nematodes removed from the stomachs of three salamanders from Laguna Quecholac were killed and fixed in hot glycerin-alcohol (nine parts 70% ethanol, one part glycerin) and cleared for study in glycerin. Representative specimens were deposited in the USNM Helminthological Collection, Beltsville, Maryland.

RESULTS AND DISCUSSION

Few reports are available on *Hedruris siredonis* in salamanders from Mexico. Baird's description of *H. siredonis* from *Ambystoma mexicanum* (Shaw, 1789), Mexico (no precise locality) proved inadequate as it was based on a single immature female specimen (see Baird, 1958). Later, Caballero and Bravo Hollis (1938) gave a detailed description of *H. siredonis* based on several mature males and females taken from *Ambystoma,* collected from Laguna Xochimilco, District Federal, Mexico, identified by them as *A. tigrinum* (Green, 1825). As pointed out by Dyer and Brandon (1973), in the absence of preserved host specimens, it is impossible to verify their actual identity. This difficulty arises because of inconsistency in older publications in aplying the specific names *tigrinum* and *mexicanum* (e.g. Freitas and Lent, 1941 a,b; see also discussion in Smith, 1969), and because both species may occur sympatrically in parts of Mexico.

Dyer and Brandon (1973) reported *Hedruris siredonis* from three species of salamanders from Mexico, namely, *Ambystoma ordinarium* Taylor, 1940 from San Jose Lagunillas, Michoacán (USNM Helm. Coll., No. 72188), *A. sp.* from Zacapu Michoacán (USNM Helm. Coll., No. 72188) and *A. subsalsum* Taylor, 1943 [=*A. tigrinum* (Green, 1825)] from Laguna Alchichica, Puebla (USNM Helm. Col., No. 72189). Later, salamanders designated as *A. subsalsum* from a neotenic population of *Ambystoma* endemic in Laguna Alchichica were compared by Brandon et al. (1981) with the holotype of *A. subsalsum* Taylor (1943) and with *A. tigrinum* from several populations in Puebla, Tlaxcala, and Hidalgo. These investigators concluded that the holotype is identifiable as *A. tigrinum* and is specifically different from the Laguna Alchichica neotenes designated as *A. taylori.* Thus, the salamander host of *H. siredonis* taken at Laguna Alchichica are *A. taylori* nec *subsalsum.* Later, Dyer (1984) reported *H. siredonis* in 5 of 34 *A. taylori* collected from Laguna Alchichica, Puebla (USNM Helm. Coll., No. 77156) amending the report by Dyer and Brandon (1973).

The salamanders designated by Dyer and Brandon (1973) as *Ambystoma sp.* from the municipality of Zacapu, Michoacán were later determined to be a new species, *Ambystoma andersoni,* by Krebs and Brandon (1984) thereby amending the report of Dyer and Brandon (1973).

Of eighty-five *Ambystoma sp.* collected from Laguna Quecholac, Laguna Atexcac and Laguna de la Mina Preciosa, three from Laguna Quecholac were infected with *H. siredonis*. Measurements of two males and five females from two *A. sp.* are as follows. Male: total length 10.9-11.7 mm; esophagus 1310-1400 μm long, nerve ring 225-240 μm, deirids 182-220 μm and excretory pore 280-300 μm from anterior extremity; spicules 180 μm long; tail 460 μm long. Female: total length 12.9-15.4 mm; esophagus 1520-1542 μm long; nerve ring 252-260 μm, deirids 250-265 μm and excretory pore 345-347 μm from anterior extremity; vulva 500-542 μm from anus; eggs 55-60 μm long and 34-38 μm wide. Embryonated eggs with fully developed larvae bear opposite peripheral swellings which are circular when viewed on end. Representative specimens are deposited in the USNM Helm. Coll., No. 804056.

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MEGALOBATRACHONEMA (CHABAUDGOLVANIA) ELONGATA (BAIRD, 1858) BAKER, 1986 (NEMATODA: KATHLANIIDAE) IN AMBYSTOMA ANDERSONI KREBS AND BRANDON, 1984 FROM ZACAPU, MICHOACAN, MEXICO

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ABSTRACT

Four of five *Ambystoma andersoni* Krebs and Brandon, 1984 endemic to Zacapu, Michoacán, Mexico were found infected with the nematode, *Megalobatrachonema (Chabaudgolvania) elongata* (Baird, 1858). This is the second report of this namatode in *A. andersoni* from this locality.

INTRODUCTION

The geographic distribution of *Megalobatrachonema (Chabaudgolvania) elongata* (Baird, 1858) Baker, 1986 (=*Leptodera elongata* Baird, 1858; *Spironoura elongata* (Baird, 1858) Walton, 1932; *Falcaustra elongata* (Baird, 1858) Freitas and Lent, 1941) has thus far been limited to ambystomatid salamanders of Mexico and the contiguous United States. This nematode was first described from *Ambystoma mexicanum* (Shaw, 1789) by Baird (1858) and assigned to *Leptodera* Dujardin, 1845. Later, Caballero and Bravo Hollis (1938) redescribed this species from *Ambystoma tigrinum* (Green, 1825) of Laguna Xochimilco, Mexico. Dyer and

Brandon (1973) pointed out, however, that in the absence of preserved host specimens, it is impossible to verify their actual identity. This difficulty arises because of inconsistency in older publications in applying the specific names *tigrinum* and *mexicanum* and because both species may occur sympatrically in parts of Mexico. Dyer and Brandon (1973) reported *(M. (C.) elongata* in several ambystomatids from Mexico. Subsequently, Dyer (1986) reported this nematode in *Ambystoma* sp. from Laguna Atexcac, Laguna Quecholac, and Laguna de la Mina Preciosa, Puebla, Mexico. The finding of this nematode in *A. tigrinum* from Utah by Fransden and Grundmann (1960) constitutes the only record of this parasite in a salamander host outside of Mexico. The present report is concerned with the detection of *M. (C.) elongata* in *Ambystoma andersoni* Krebs and Brandon (1984) endemic to Zacapu, Michoacán, Mexico.

MATERIALS AND METHODS

Five *Ambystoma andersoni* obtained in the municipality of Zacapu, Michoacán, Mexico during July 1981 were examined for helminth parasites. Nematodes were killed and fixed in hot glycerin-alcohol (nine parts 70% ethanol and one part glycerin) and cleared for study in glycerin. Representative specimens were deposited in the United States National Museum Helminthological Collection.

RESULTS AND DISCUSSION

Dyer and Brandon (1973) reported *M. (C.) elongata* in *Ambystoma lacustris* Taylor and Smith, 1945 from Laguna Zumpango, Mexico (USNM Helm. Coll., No. 72190), *Ambystoma* sp. from Zacapu, Michoacán, Mexico (USNM Helm. Coll., No. 72191), *Ambystoma tigrinum* (Green, 1825) (=*A. subsalsum* Taylor, 1943) from Laguna Alchichica, Puebla, Mexico (USNM Helm. Coll., No. 72192), Nopaltepec, Mexico (USNM Helm. Coll., No. 72193), *Rhyacosiredon altamirani* from La Marquesa, Mexico (USNM Helm. Coll., No. 72194) and *A. tigrinum* from Xochimilco, Mexico (specimens deposited, SIUC Helm. Coll., No. 52A.0 but inadvertently not reported).

Salamanders designated as *A. subsalsum* from a neotenic population of *Ambystoma* endemic to Laguna Alchichica were compared by Brandon et al. (1981) with the holotype of *A. subsalsum* and with *A. tigrinum* from several populations in Puebla, Tlaxcala, and Hidalgo. They concluded that the holotype is identifiable as *A. tigrinum* and is specifically different from the Laguna Alchichica neotenes designated as *A. taylori.* Thus, the salamander hosts of *M. (C.) elongata* taken at Laguna Alchichica are *A. taylori* nec *subsalsum* as reported by Dyer and Brandon (1973).

Salamanders designated by Dyer and Brandon (1973) as *Ambystoma* sp. from the municipality of Zacapu, Michoacán were later determined by Krebs and Brandon (1984) to be a new species, *Ambystoma andersoni,* thereby amending the report of Dyer and Brandon (1973).

The present finding constitutes the second report of *M. (C.) elongata* in *A. andersoni* from Zacapu, Michoacán. Measurements of two males and five females are as follows. Male: total length 19.2 to 22.1 mm; esophagus 2200 to 3100 μm long; nerve ring 500 to 580 μm and excretory pore 1780 to 1810 μm long from anterior

extremity; spicules 590 to 608 μm long; gubernaculum 142 to 153 μm long; tail 640 to 710 μm long. Female: total length 27.2 to 33.0 mm long; esophagus 2528 to 2883 μm long; nerve ring 530 to 690 μm, excretory pore 2252 to 2410 μm, and vulva 18.0 to 23.6 mm long from anterior extremity; tail 1020 to 1264 μm long. Representative specimens are deposited in the USNM Helm. Coll., No. 80408.

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HABITAT USE BY CANADA GEESE IN THE KASKASKIA RIVER VALLEY OF ILLINOIS

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ABSTRACT

A habitat use survey route was driven 14 times in the Kaskaskia River bottoms near Vandalia, Illinois from late February — early March, 1988. A total of 131,900 Canada geese (*Branta canadensis*) in 141 flocks was observed. Habitat use was highest in corn (46.2%), wetlands (24.6%), and winter wheat (21.3%). An average of 68% of geese were observed feeding, and 15% resting. High percentage feeding compared to wintering geese suggested birds were entering spring hyperphagia.

INTRODUCTION

Geese are known to gain substantial lipid and protein reserves needed for reproduction by changing food habits and habitat use and increasing feed activity (hyperphagia) during spring migration (McLandress and Raveling 1981, Thomas 1983). Considerable data have been gathered concerning habitat use and activities of Mississippi Valley Population (MVP) Canada geese wintering on southern Illinois refuges, and during spring staging in Wisconsin (Paine and Tacha 1987; Pritchert 1988; Unpubl. data, Coop. Wildl. Res. Lab., So. Ill. Univ.). However, little is known about habitat availability or needs of geese at early spring staging areas in central and northern Illinois.

Radiotelemetry data from 1986-87 indicate the Kaskaskia River Valley between Lake Shelbyville and Carlyle Lake in Illinois annually receives over 2 million goose-use days directly after goose departure from southern Illinois refuges in late February — early March (Unpubl. Data, Coop. Wildl. Res. Lab., So. Ill. Univ.).

Our purpose was to document habitat availability and use by Canada geese in this area during spring, 1988.

STUDY SITE AND METHODS

The Kaskaskia River flows south through central Illinois, and is the water source for both Lake Shelbyville and Carlyle Lake. This study took place north of Carlyle Lake in Fayette County, including lands up to 5 km east and west of the Kaskaskia River. The area is characterized by large bottomland crop fields and steep hills.

A circular 83 km habitat route representative of available habitats in the area was established between Vera, Illinois and Carlyle Lake Waterfowl Management Area (CLWMA) subimpoundments, with Vandalia, Illinois as the approximate center. Habitat availability was assessed within 0.8 km of the route through cover mapping. The route was driven between sunrise and sunset 23 and 26-28 February and 5-6 March 1988, 2-3 times daily for a total of 14 routes. For each goose flock observed, flock size, habitat type, and flock activity were recorded. Weather conditions during the study were normal, with the average daily temperature being 2°C.

Habitat availability was summarized as percentage of total ha available for goose use in each of 8 habitat types. Habitat use was determined by recording the percentage of geese observed in each habitat type. Proportional use divided by proportional availability yielded a Selectivity Index (SI) for each habitat.

Flock behavior was separated into 6 categories: alert, comfort, feed, locomotion, rest, and other. Behavior data were summarized as the overall mean percentage of geese exhibiting each behavior, and mean percentage of each behavior by habitat type. Differences in behavior by habitat were compared using Analysis of Variance (ANOVA). Duncan's Multiple Range Test clarified significant ($P < 0.05$) variation.

RESULTS AND DISCUSSION

A total of 29,142 ha was established as available for goose use on the habitat route. Soybeans and corn accounted for 68.2% of the available land, winter wheat 18.2%, other forage 6.7%, and wetland 5.4%. Included in the wetland category was a portion of the CLWMA subimpoundment that was planted to corn before flooding. Milo, alfalfa/clover, and other grain comprised the remaining 1.5%.

Habitat use (Table 1) was highest in corn (46.2%), wetland (24.6%), and winter wheat (21.3%); milo, other grain, and alfalfa/clover received no use. These data are consistent with habitat use by geese during winter in southern Illinois and spring staging in Wisconsin, with the exception that use of alfalfa/clover was much lower (Bell and Klimstra 1979; Paine and Tacha 1987; Pritchert 1988; Unpubl. data, Coop. Wildl. Res. Lab., So. Ill. Univ.).

Wetland was the only habitat significantly ($P < 0.05$) selected for, while soybeans were used in proportions lower ($P < 0.05$) than availability. Paine and Tacha (1987) and Pritchert (1988) found that geese wintering in southern Illinois selectively used winter wheat, alfalfa/clover, and wetland, but underutilized soybeans, milo, and other forage.

Feeding and resting comprised 83% of diurnal flock activity (Table 2). Feeding averaged 68%, and was greater in corn (66%), soybeans (71%), and winter wheat (87%) than in other forage or wetland (ANOVA; F=3.8; df=4,90; $P < 0.007$). Rest did not vary significantly by habitat (ANOVA; F=1.84; df=4,90; $P > 0.127$), and averaged 15%. Alert, comfort, and locomotion were approximately equal and constituted 15% of total activities. Pritchert (1988) found overall percentages of 31% feeding and 38% resting. Because these percentages include wetlands, which at Rend Lake is primarily lake habitat, and in this study included flooded corn stubble, mean percentage feeding was compared excluding wetland habitat. This resulted in wintering geese averaging 57% feeding (Pritchert 1988), while in this study feeding averaged 65%.

CONCLUSIONS AND RECOMMENDATIONS

Habitat use by Canada geese in the Kaskaskia River Valley was consistent with habitat use during winter in southern Illinois and spring staging in Wisconsin. However, activity data indicated increased feeding and decreased resting compared to geese wintering in southern Illinois. This increased feeding suggests geese in the Kaskaskia River Valley are already entering active hyperphagia that leads to protein and lipid deposition in preparation for reproduction. This area is an important early spring staging area for MVP geese; efforts to insure an adequate supply of waste grain and forage crops during spring are encouraged.

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Table 1. Habitat availability and use by Canada geese in the Kaskaskia River bottoms in central Illinois during spring, 1988.

Habitat[a]	Available ha	Available %	Mean % use (SE)	Selectivity index
Corn	9,923	34.0	46.2(0.1)	1.4
Soybeans	9,966	34.2	6.7(0.0)	0.2[b]
Milo	85	0.3	0.0	0.0
Other Grain	246	0.8	0.0	0.0
Winter Wheat	5,296	18.2	21.3(0.0)	1.2
Alfalfa/Clover	111	0.4	0.0	0.0
Other Forage	1,950	6.7	1.2(0.0)	0.2
Wetland	1,564	5.4	24.6(0.1)	4.6[b]
TOTAL	29,142	100.0	100.0	

[a]Does not include roads, residential areas, forest, and other habitats considered unavailable to geese.
[b]Proportional use significantly different from availablity (Z - tests, $P<0.05$).

Table 2. Diurnal activities of Canada geese in Kaskaskia River bottoms in central Illinois during spring, 1988.

Habitat[a]	Mean % (SE) activities: Feed	Rest	Comfort	Locomotion	Alert	Other
Corn	66(5)AB	14(4)A	6(2)B	5(1)B	7(2)AB[b]	2(0)A
Soybeans	71(6)AB	20(6)A	3(1)B	3(1)B	2(0)B	1(0)A
Winter Wheat	87(1)A	4(1)A	2(1)B	3(0)B	3(1)B	1(0)A
Other Forage	36(10)B	9(4)A	3(0)B	40(23)A	11(8)A	1(0)A
Wetland	44(10)B	24(7)A	19(7)A	10(4)B	3(1)B	1(1)A
Overall $\bar{x}$	68(3)	15(2)	6(1)	5(1)	4(1)	2(0)

[a]No geese were observed in milo, other grain, or alfalfa/clover habitats.
[b]Different letters within columns denote significantly different ($P<0.05$) means, Duncan's Multiple Range Test.

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AN ADDITIONAL SPECIMEN OF TERRAPENE CAROLINA TRIUNGUIS (REPTILIA: TESTUDINES) FROM SOUTHERN ILLINOIS

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ABSTRACT

A third confirmed specimen of *Terrapene carolina triunguis* is reported for the state of Illinois. This specimen may represent a free-ranging individual from adjacent Missouri. This finding raises interesting questions regarding distributions of and potential gene flow among the two species and two subspecies of box turtles that occur in Illinois.

INTRODUCTION

The three-toed box turtle (*Terrapene carolina triunguis)* occurs from western Georgia to northeastern Texas, northward from northern Louisiana west of the Mississippi River through Arkansas, the eastern half of Oklahoma and throughout most of Missouri (Pope, 1939; Conant, 1975). North of Tennessee, the Mississippi River apparently forms a boundary between the ranges of *T. c. triunguis* and *T. c. carolina,* with *T. c. triunguis* occurring on the Missouri side of the river and *T. c. carolina* occurring in Illinois (Pope, 1939; Smith, 1961).

To date, there have been two confirmed specimens of *T. c. triunguis* collected in Illinois. One specimen collected in northern Illinois is undoubtedly an introduced specimen (Dancik, 1974). Smith (1961) described the earliest recorded specimen

(collected in Calhoun County) as being "unquestionably" *T. c. triunguis* and further states, "This single example may be a waif, or possibly the population between the Mississippi and nearby Illinois rivers consists of intergrades, in which the characters of *triunguis* are recessive to those of *carolina*." Garman (1892) also reported that both *T. c. triunguis* and *T. c. carolina* occurred in Illinois, but no specimens are available to substantiate this report. Several additional specimens of *T. c. triunguis* also have been collected (M. Morris, pers. comm.), but it is, again, uncertain whether or not these specimens are naturally occurring.

In this paper we describe a third specimen of *T. c. triunguis* collected in southern Illinois.

DESCRIPTION AND DISCUSSION

One specimen identified as *Terrapene carolina triunguis* was collected 7 September 1987 as it was crossing Illinois Route 3 approximately 3.81 km north of Olive Branch, Alexander County. This site is approximately 4.8 km due east of the Mississippi River. The specimen is a subadult male (plastron length 90 mm; plastron width 50 mm) with a keeled carapace and flared posterior marginals. The coloration of the specimen is: olive brown carapace with a diffuse, yellow radiating pattern; uniform yellow plastron; and several distinct yellow spots on the sides of the head posterior to the eyes. There are three digits on each of the hind limbs. Independent confirmation of the identification of this specimen has been provided by L. E. Brown. The specimen was then photographed and released near the original collection site. Photographic slides of the specimen are in the herpetological collection of the Illinois Natural History Survey.

While it is possible that this specimen represents an individual that was transported from within the natural range of *T. c. triunguis* and released in Illinois, we feel there is substantial evidence that this specimen could be naturally occurring. First, while there are various reports as to the swimming ability of *T. carolina*, it is generally agreed upon that this species can swim (Ditmars, 1930; Barker, 1964) and may, in fact, swim quite well (Cahn, 1937). Second, it is generally uncommon for rivers to limit the distributions of turtles (Pope, 1939). Finally, certain individuals of *T. c. triunguis* are free-ranging, move almost constantly, and are capable of traveling long distances (Kiester et al., 1982).

These factors, in conjunction with the close proximity of the Mississippi River to where the specimen was collected, lead us to believe that there is a very good possibility that this specimen represents a free-ranging, naturally-occurring individual.

This represents a second case where the three-toed box turtle could have crossed the Mississippi River. A crossing is more likely because the river passes through a narrow gorge just upstream, at Thebes. The larger river and broader flood plain might theoretically be more of a barrier to the south, but *T. c. triunguis* occurs extensively on both sides there. It would be helpful to check the east bank of the Mississippi River in Kentucky. Barbour (1971) says that only *T. c. carolina* occurs in Kentucky, but that a small percentage from western Kentucky do have three toes on the hind feet, "showing evidence of intergradation." It should be noted that a ferry has crossed the river for many years at Golden Eagle, in Calhoun

County, Illinois, which raises the chances that Smith's specimen was transported across.

If *T. c. triunguis* can cross the Mississippi River into Illinois, intergrades with *T. c. carolina* would be expected, since subspecies are supposed to be able to interbreed. Barbour (1971) mentioned some apparent intergrades elsewhere, and Pope (1939) says that "presumably" and "apparently" they interbreed elsewhere, but he does not report or describe any intergrades. Smith (1961) suggests that "possibly" intergrades occur in Illinois, but didn't report finding any. The distribution and genetic relationships of box turtles in southern Illinois are of considerable interest in that hybridization between *T. carolina* and *T. ornata* also may occur in this region. *Terrapene ornata* occurs throughout most of the state of Missouri and as far south in Illinois as Jackson and Franklin counties (Smith, 1961). Presumed Illinois hybrids have been reported by Smith (1955). Further, presumed hybrids have been collected in Indiana (Clark, 1935) and Missouri (Shannon and Smith, 1949). Collins (1974) has suggested that *T. c. triunguis* and *T. ornata* may hybridize in Kansas.

The lack of specimens of *T. c. triunguis* from southern Illinois raises several interesting questions regarding both biogeography and genetics of this subspecies in Illinois and merits further investigation.

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NEW ALGAL RECORDS FOR HANCOCK AND HENDERSON COUNTIES FROM POOL 19, UPPER MISSISSIPPI RIVER

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ABSTRACT

Planktonic, sub-generic algal taxa were collected and identified from the main channel to the east side of Pool 19, upper Mississippi River, within the political borders of Hancock and Henderson Counties, Illinois. Eighty-three new algal records are noted for Hancock County and 86 new records for Henderson County. One species, previously unreported in the state of Illinois, was found in both Hancock and Henderson Counties.

INTRODUCTION

Algal taxa reported in the following checklist were found in monthly samples taken during the period October, 1982, to August, 1983, from Navigation Pool 19 of the upper Mississippi River.

Pool 19 is a 74.5-km river reach which divides Lee and Des Moines Counties of Iowa from Hancock and Henderson Counties of Illinois, with the main channel serving as a political border for these states. Taxa reported in this checklist were collected from the Illinois (eastern) side of the river. No taxa found only on the Iowa (western) side of Pool 19 are reported.

Voucher samples of concentrated phytoplankton are in the Algal Section of the R. M. Myers Herbarium (MWI), Western Illinois University, Macomb.

ANNOTATED CHECKLIST OF SPECIES

Nomenclature follows that of Boyer (1927), Collins (1928), Smith (1950), Drouet and Daily (1956), Prescott (1962), Cleve (1965), Cholnoky (1966), Patrick and Reimer (1966), Cleve-Euler (1968), Drouet (1968), Huber-Pestalozzi (1968), Smith (1968a and 1968b), Gerloff and Cholonky (1970), Boyer (1973), Drouet (1973), Patrick and Reimer (1975), Prescott (1978), and Bold and Wynne (1985). Determination of a county record is contingent on prior reports in Galtsoff (1924), Britton (1945), Tiffany and Britton (1971), or Dodd (1987).

Occurrence of *Nitzschia longissima* (Breb.) Ralfs constitutes the first record of this species in Illinois.

	County Record for	
	Hancock	**Henderson**
BACILLARIOPHYTA		
Achnanthes exilis Kuetz.	*	
Asterionella formosa Hass. var. *formosa*		*
Cocconeis pediculus Ehr.		*
Didymosphenia geminata (Lyngb.) Schmidt	*	
Epithemia sorex Kuetz.		*
Gomphonema olivaceum (Lyngb.) Kuetz.	*	*
Gomphonema parvulum (Kuetz.) Grun.		*
Gyrosigma scalproides (Rabh.) Cl.	*	*
Gyrosigma spencerii (Querk.) Griff. & Henfr.	*	*
Hantzschia amphioxys (Ehr.) Grun.	*	*
Melosira italica (Ehr.) Kuetz.	*	*
Meridion circulare (Grev.) Ag.		*
Navicula cryptocephala Kuetz.	*	*
Navicula elginensis (Greg.) Ralfs	*	*
Navicula exigua Greg. *ex* Grun.	*	*
Navicula protracta Grun.	*	*
Navicula seminulum Grun.	*	*
Nitzschia acicularis (Kuetz.) Wm. Sm.	*	*
Nitzschia denticula Grun.	*	*
Nitzschia linearis Wm. Sm.	*	*
Nitzschia longissima (Breb.) Ralfs	*	*
Nitzschia palea (Kuetz.) Wm. Sm.	*	*
Nitzschia sigmoidea (Nitz.) Wm. Sm.	*	
Nitzschia vermicularis (Kuetz.) Rabh.	*	*
Pinnularia brebissonii (Kuetz.) Rabh.		*
Rhoicosphenia curvata (Kuetz.) Grun.	*	*
Surirella angusta Kuetz.		*
Surirella didyma Kuetz.		*
Surirella linearis Wm. Sm.	*	*

	County Record for	
	Hancock	Henderson
Surirella ovata Kuetz.	*	*
Synedra acus Kuetz.	*	*
Synedra rumpens Kuetz.	*	
Synedra ulna (Nitz.) Ehr.	*	*
Tabellaria fenestrata (Lyngb.) Kuetz.	*	*
CHLOROPHYTA		
Actinastrum hantzschii var. *fluviatile* Schroed.		*
Ankistrodesmus braunii (Naeg.) Brunn.		*
Ankistrodesmus falcatus (Corda) Ralfs	*	*
Carteria multifilis (Fres.) Dill	*	*
Chodatella ciliata (Lag.) Lemm.	*	*
Chodatella quadriseta Lemm.	*	*
Closteriopsis longissima Lemm.	*	*
Closterium dianae Ehr.	*	*
Closterium ehrenbergii Menegh.	*	
Closterium gracile Breb. var. *gracile*	*	*
Closterium gracile var. elongatum West & West		*
Closterium intermedium Ralfs	*	*
Coelastrum microporum Naeg.	*	*
Crucigenia quadrata Morren	*	*
Crucigenia tetrapedia (Kirchn.) West & West	*	*
Dictyosphaerium ehrenbergianum Naeg.	*	*
Dictyosphaerium pulchellum Wood	*	*
Dispora crucigenioides Printz		*
Golenkinia radiata (Chod.) Wille	*	*
Gonium pectorale Muell.	*	*
Gonium sociale (Duj.) Warm.	*	
Kirchneriella elongata G.M. Sm.	*	
Kirchneriella lunaris (Kirchn.) Moeb.	*	
Micractinium pusillum Fres.	*	*
Oocystis borgei Snow	*	*
Pandorina morum Bory	*	*
Pediastrum boryanum (Turp.) Menegh. var. *boryanum*	*	*
Pediastrum boryanum var. *longicorne* Raciborski		*
Pediastrum tetras (Ehr.) Ralfs	*	*
Phacotus lenticularis (Ehr.) Stein	*	*
Polyedriopsis spinulosa Schmidle	*	*
Pteromonas aculeata Lemm.	*	*
Scenedesmus acuminatus (Kirchn.) Chod.		*
Scenedesmus bijuga (Turp.) Lag.	*	*
Scenedesmus brasiliensis Bohlin	*	*
Scenedesmus denticulatus Lag.	*	

	County Record for	
	Hancock	Henderson
Scenedesmus dimorphus Kuetz.	*	*
Schroederia setigera (Schroed.) Lemm.	*	*
Sphaerocystis schroeteri Chod.	*	*
Staurastrum gracile Ralfs		*
Staurastrum oxyacanthum Arch.	*	
Tetraedon caudatum (Corda) Hansg.	*	*
Tetraedon minimum (A. Br.) Hansg.	*	*
Tetraedon muticum (A. Br.) Hansg.	*	*
Tetraedon pentaedricum West & West	*	
Tetraedon regulare Kuetz.	*	
Tetraedon trigonum (Naeg.) Hansg. var. *trigonum*	*	*
Tetraedon trigonum var. *gracile* (Reinsch) DeT.	*	*
Tetrastrum staurogeniaforme (Schroed.) Lemm.	*	*
CHRYSOPHYTA		
Mallomonas acaroides Perty		*
CRYPTOPHYTA		
Cryptomonas erosa Ehr.	*	*
CYANOPHYTA		
Anabaena spiroides Kleb.		*
Anacystis incerta (Lemm.) Dr. & Daily	*	*
Anacystis marina (Hansg.) Dr. & Daily	*	*
Anacystis montana (Lightf.) Dr. & Daily	*	
Anacystis thermalis (Menegh.) Dr. & Daily	*	*
Anacystis thermalis f. *major* (Lagerh.) Dr. & Daily		*
Coccochloris stagnina Spreng.	*	
Gomphosphaeria lacustris Chod.	*	*
Raphidiopsis curvata Fritsch & Rich	*	
Schizothrix calcicola Gom.	*	*
Spirulina subsala Oerst.	*	
EUGLENOPHYTA		
Phacus acuminata Stokes		*
Phacus longicauda (Ehr.) Duj.		*
Trachelomonas hispida (Perty) Stein		*
Trachelomonas schauinslandii Lemm.	*	*
Trachelomonas similis Stokes	*	
Trachelomonas volvocina Ehr.	*	

	County Record for	
	Hancock	Henderson
PYRRHOPHYTA		
Peridinium quadridens Stein		*
XANTHOPHYTA		
Ophiocytium capitatum Wolle	*	*
Ophiocytium cochleare (Eichw.) A. Br.	*	

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NEW PEORIA RECORDS FOR AGRAULIS VANILLAE NIGRIOR MICHENER (LEPIDOPTERA: NYMPHALIDAE) AND ERINNYIS OBSCURA F. (LEPIDOPTERA: SPHINGIDAE).

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ABSTRACT

Peoria County occurrence of two Lepidoptera species with Southern affinities is reported for the first time. *Erinnyis obscura* was collected for Dunlap, on the date 8 October 1986. *Agraulis vanillae* was collected approximately 6 kilometers from Peoria on the date 7 August 1987.

INTRODUCTION

Both the Gulf Fritillary, *Agraulis vanillae nigrior* and the Obscure Sphinx, *Erinnyis obscura* are Lepidoptera with subtropical affinities, which normally occur in the southern United States from Florida to Texas. Both species have been reported from northern states on rare occasions. Irwin and Downey (1973) reported 6 records for *A. vanillae* in the state of Illinois, including a report of larvae from Madison County. The northern-most records from Kane, Cass, and Champaign Counties are thought to be strays (Irwin and Downey, 1973). Sedman and Hess (1985) reported no new findings during the years 1976 and 1983. The Obscure Sphinx. (*E. obscura*) has been reported to stray as far north as Kansas and New Jersey between the months of September and October (Covel, 1984). I can find no substantiated records of its occurrence in Illinois after checking collections at the

Illinois Natural History Survey in Urbana, Lakeview Museum of Arts and Sciences in Peoria, Illinois, as well as the private collections of Dr. H. Princen, Mr. Gordon Adams, Kevin Russell and Dr. Michael Toliver of Eureka. However, I sighted but did not capture a specimen in September, 1980 in Carbondale, Jackson County. No literary references have been found that reported occurrences in Peoria Co., Illinois.

SPECIMEN ACCOUNTS

On 8 October 1986, while collecting at Dunlap High School in Dunlap, Illinois, I collected a single male of *Erinnyis obscura* on the west wall of the school gym, beneath a Mercury vapor light. The recorded time was at 24:00 hrs. and the temperature was about 13°C. (Figure 1.)

On 7 August 1987, I sighted a male of *Agraulis vanillae* sampling the composites in our flower garden at 1703 S. Cameron Lane. Time of sighting was at 17:15 and the temperature was about 26°C. I initially missed capturing the butterfly. It returned approximately five minutes later and fed at some Dahlia's before I captured it. (Figure 2.)

ACKNOWLEDGMENTS

I wish to thank the Illinois Natural History Survey, Lakeview Museum in Peoria, Dr. Princen, Mr. Gordon Adams, and Kevin Russell of Peoria, and Dr. Michael Toliver of Eureka for allowing me to check their collections and for advice on this paper. I would also like to thank my father, Dr. Clarence E. Prill for photographing the specimens.

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Figure 1. Male specimen of *Errinnyis obscura F.* collected at Dunlap, Peoria Co., IL on 8 October 1986.

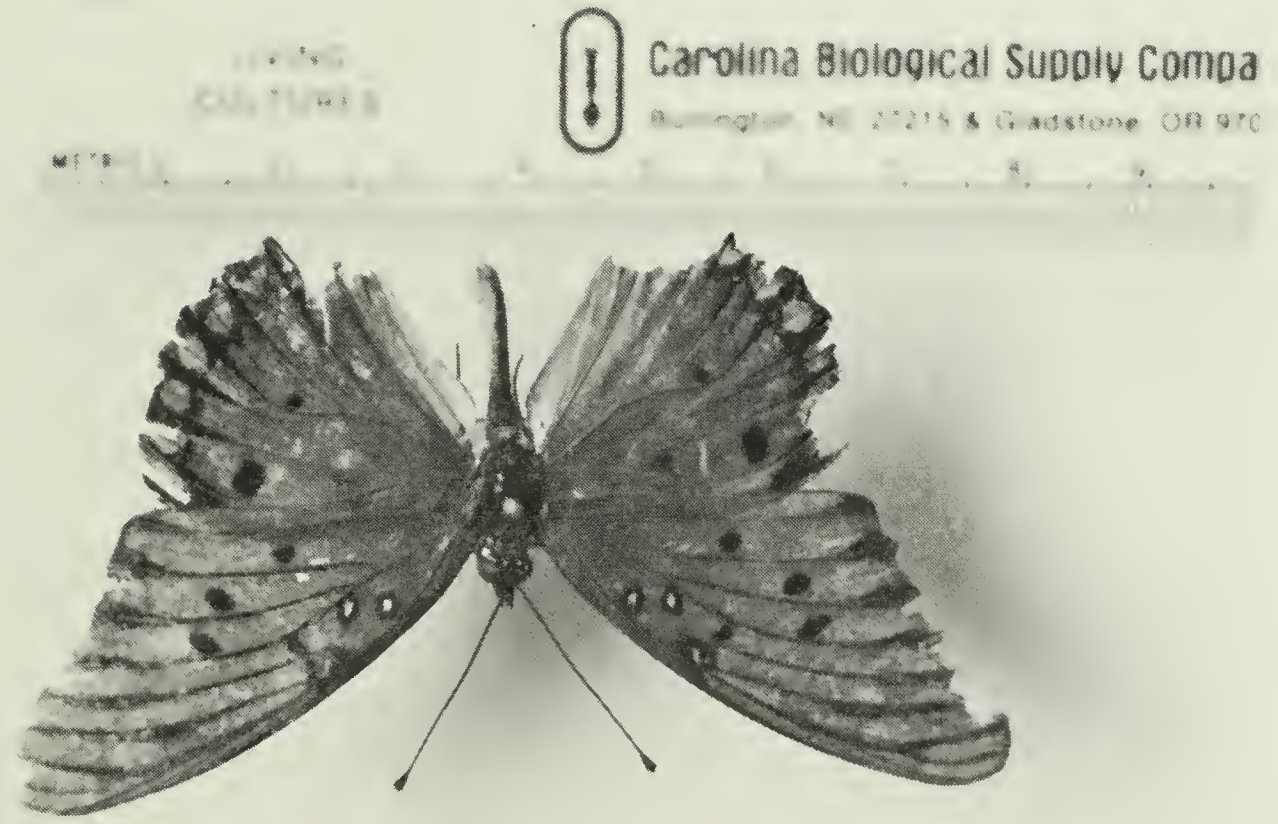

Figure 2. Male specimen of Agraulis vanillae Michener, collected at 1703 S. Cameron Lane, Peoria Co., IL, on 7 August 1987.

CORRIGENDUM

RE: Buhnerkempe, J. E. and R. L. Westemeier. 1988. Breeding biology and habitat of upland sandpipers on prairie-chicken sanctuaries in Illinois. Transactions of the Illinois Academy of Science (1988). Volume 81, 1 and 2, pp. 153-162.

The captions for Figures 1-4 which were omitted should read as follows:

FIGURE 1. Numbers of upland-sandpiper nests observed and expected in various cover types on prairie-chicken sanctuaries in Jasper County, Illinois, from 1963 through 1984. (RT = redtop-timothy, SB = smooth brome, PR = prairie grass, GF = mixed grasses and forbs, LG = legumes).

FIGURE 2. Numbers of upland-sandpiper nests observed and expected in cover according to type of management conducted prior to the nesting season on prairie-chicken sanctuaries in Jasper County, Illinois, from 1963 through 1984. (UND = undisturbed, MS = mowed for seed harvest, MH = mowed for hay, RM = rotary mowed, PB = prescribe burned).

FIGURE 3. Numbers of upland-sandpiper nests observed and expected in fields according to the season of growth since seeded on prairie-chicken sanctuaries in Jasper County, Illinois, from 1963 through 1984.

FIGURE 4. Fluctuations in upland-sandpiper nest densities from 1963 through 1984 on prairie-chicken sanctuaries in Jasper County, Illinois.

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